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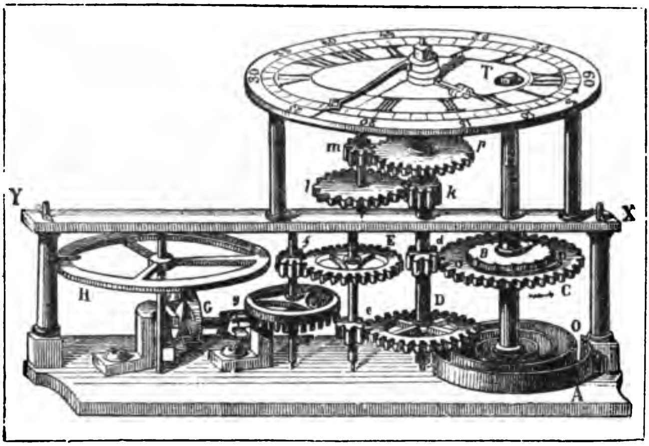
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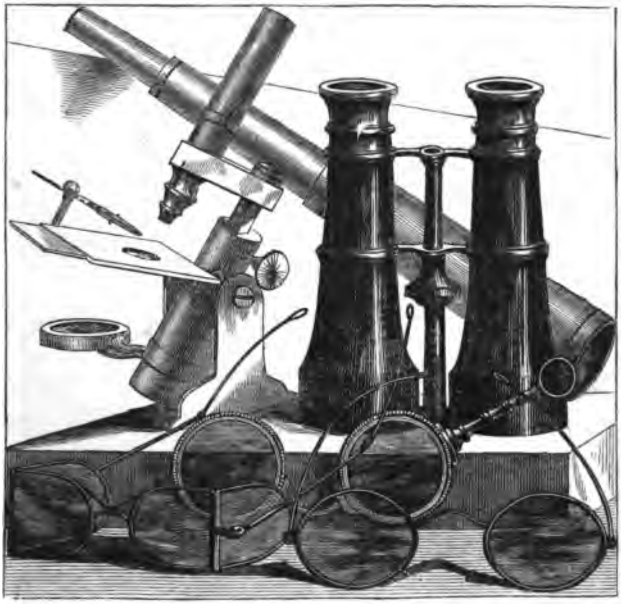

COMMON THINGS

EXPLAINED.

By DIONYSIUS LARDNER, D.C.L.,
Formerly Professor of Natural Philosophy and Astronomy in University College London.

CONTAINING:

AIR.
EARTH
FIRE.
WATER.
TIME.
THE ALMANACK
CLOCKS AND WATCHES
SPECTACLES.
COLOUR.
KALEIDOSCOPE.
PUMPS.

FROM

"THE MUSEUM OF SCIENCE AND ART."

WITH ONE HUNDRED AND FOURTEEN ILLUSTRATIONS.

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CONTENTS.

*** *As this book is not paged, the figures in the Table of Contents refer to Paragraphs, and not to Pages.*

AIR.

1. Air most necessary to existence.—2. Respiration.—3. Fresh air necessary.—4. Air is material.—5. Its weight and momentum.—6. How weighed.—7. The atmosphere.—8. Its pressure.—9. Why bodies not crushed by it.—10. Illustrated by a cupping-glass.—11. Compressibility.—12. Elasticity.—13. Elastic pressure.—14. Varies with the density.—15. Strata of atmosphere near the surface of the earth and at greater elevations—Diminished pressure at great elevations.—16. Anciently supposed to be an element.—17. Air a compound.—18. Gases.—19. Proportion of the constituents of air.—20. Azote or nitrogen.—21. Oxygen gas.—22. Combustion.—23. Its products.—24. Carbonic acid.—25. Unfit for respiration.—26. Impure air produced in warming and lighting.—27. Ventilation of public buildings.—28. Carbonic acid in effervescing liquors.—29. Is generated in all spontaneous changes of dead matter.—30. Choke-damp.—31. Is diffused through the atmosphere.—32. Evolved in respiration.—33. Vital air.—34. Air poisoned in crowded rooms.—35. Necessity of ventilation.—36. Air not absolutely transparent or colourless.

EARTH.

1. Difficulty of observing the earth as a whole.—2. It appears at first an indefinite flat surface.—3. This disproved by travelling round it.—4. Proof of the curvature of its surface by observation of distant objects at sea.—5. By the earth's shadow projected on the moon.—6. Inequalities of surface, such as mountains and valleys, insignificant.—7. Magnitude of earth, how ascertained.—8. Length of a degree of latitude.—9-10. Illustrations of the earth's magnitude.—11. Is the earth at rest?—12. Apparent motion of the firmament.—13. Origin of the word "Universe."—14. This apparent motion may not be real, may arise from a rotation of the earth.—15. How such a rotation would produce it.—16. Poles.—17. Equator.—18. Hemi-

spheres. — 19. Meridians. — 20. Which of the two rotations is the more probable?—21. Rotation of the universe impossible.—22. Simplicity of the supposed rotation of the globe.—23. Direct proofs of this motion.—24. Foucault's experiment.—25. Its analogy to the planets.—26. Conclusion as to the globular form of the earth requires modification. — 27. All human knowledge tentative and approximative.—28. Rotation not compatible with the exact globular form.—29. Centrifugal force of the earth's rotation.—30. The globe rotating would assume the form of an oblate spheroid.—31. The degree of ellipticity would vary with the velocity of rotation.—32. Experimental illustration. — 33. Ellipticity corresponding to the diurnal rotation.—34. How these circumstances affect the actual state of the earth.—35. Form of a terrestrial meridian.—36. Dimensions of the terrestrial spheroid.—37. Its departure from an exact globe very small.—38. Its density and mass.—39. Determined by Cavendish and Maskelyne.—40. Its total weight.

FIRE.

1. Fire an ancient element.—2. Combustion.—3. Fuel.—4. Carbon.—5. Hydrogen.—6. Charcoal fire.—7. Its effect on the air.—8. Experimental illustration of combustion of charcoal.—9. Combustion of hydrogen.—10. How the combustion is continued.—11. Carbon burns without flame.—12. What is flame?—13. Combustion of hydrogen produces water.—14. All combustibles produce carbonic acid and water.—15. Carburetted hydrogen.—16. Carbon renders flame white.—17. Olefiant gas.—18. Light carburetted hydrogen.—19. Fire-damp.—20. Will-o'-the-Wisp.—21. Experimental illustration.—22. Heavy carburetted hydrogen.—23. Pit-coal.—24. Coal-fire explained.—25. Products of its combustion.—26. Its effect on the air.—27. Wood-fuel.—28. Combustibles used for illumination.—29. Their effect on the air.—30. Construction of grates and chimneys.—31. Analysis of a common coal-fire.—32. It warms and ventilates.—33. Necessity for ventilation.—34. Injurious effect of plants at night.—35. Effect of crowded and brilliantly lighted rooms.—36. Explanation of the burning of a candle.—37. And of lamps.

WATER.

1. Water may be solid, liquid, or vapour.—2. Colourless and tasteless.—3. Its weight.—4. Expands by heat.—5. Point of greatest density.—6. Freezing point.—7. Boiling.—8. Evaporation.—9. Heat absorbed in evaporation. — 10. Superficial evaporation.—11. Saturation of air by vapour.—12. Process of drying.—13. Case of roads and paths.—14. Drying linen.—15. Wind promotes drying.—16. Water never naturally pure.—17. Contains fixed air.—18. And other substances in solution.—Hard water.—19. Soft water.—20. Mineral springs.—21. Filtration. — 22. Filtering-paper.—23. Artificial filters.—24. Water not absolutely colourless.—25.

CONTENTS.

How to obtain water absolutely pure.—26. Rain-water nearly so. —27. River-water—Thames-water. —28. Water not an element—Its composition. —29. Methods of purifying it.—30. Distillation of water.—31. Conversion of vapour into water.—32. Weight of vapour.—33. Condensation.—34. Distilling apparatus.—35. Composition and decomposition.—36. Oxygen and hydrogen.—37. Hydrogen.—38. Fitted for balloons. —39. Inflammable.—40. Water produced by combining oxygen and hydrogen.—41. Apparatus for this experiment.—42. Composition of Water.—43. Analysis of water.—44. By voltaic current.—45. By other methods.—46. By potassium and sodium.—47. By iron.

TIME.

CHAP. I.—1. Simple notions difficult to define.—2. Conception of time, how obtained.—3. By succession of sensible impressions.—4. Proof that such succession is necessary. —5. Time passes faster with some than with others.—6. Is measured only by a regular and uniform succession.—7. Periodic phenomena which may measure time.—8. Natural appearances intended for that purpose.—9. Significations of the word "day."—10. Hours.—11. Their length in certain cases variable.—12. Vulgar and equinoctial hours.—13. Commencement of the day with different nations.—14. Italian time.—15. Inconvenience of such a mode of reckoning. —16. Modern method.—17. Civil and astronomical time.—18. The day the standard unit.—19. Necessary to determine it rigorously.—20. What is a day?—21. Diurnal rotation of the heavens.—22. Its constancy and uniformity.—23. Nevertheless not fitted to be the unit of civil time.—24. The meridian.—25. Diurnal motion of the sun—Means of observing it.—26. Transit instrument.—27. Method of observing with it.—28. Sidereal day—Its subdivisions.—29. Its permanency and uniformity—Unfit, nevertheless, for a measure of time. —30. Why the sun is not fit.

CHAP. II.—31. How to observe the sun's transits.—32. Interval between them variable.—33. Mean and apparent time.—34. Relative changes of mean and apparent time. —35. The days on which they coincide.—36. The equation of time.—37. Further explained.—38. Its extreme error.—39. Mean Time adopted in France.—40. Unfitness of apparent Time.—41. Local time varies with longitude.—42. Equalisation of local Time proposed.—43. How time-pieces are regulated.—44. Mean solar hours, minutes, and seconds.—45. Length of sidereal day.—46. The week.—47. Opinions as to its origin.—48. Both opinions erroneous.—49. Origin of the names of the days.—50. First day of the week.—51. The month.

CHAP. III.—The month (continued). —52. Not conformable with lunar periods.—53. Difficulty of subdividing the year.—54. Division unequal.—55. Egyptian months. —56. Greek.—57. Solon's months. —58. Roman months—Romulus. —59. Origin of names of months. —60. Additional months of Numa. —61. Origin of their names.—62. Their lengths.—63. Superstition in favour of odd numbers—Methods of remembering the lengths of the months.—64. Calends.—65. Greek Calends.—66. Nones.—67. Ides.

—68. Practice of counting backwards. — 69. Discordance of the Roman year with the seasons.——70. Month Mercedonius.—71. Legal meaning of "month."—72. The year.—73. What is a year? —74. Egyptian.—75. Only a rude approximation to the course of the seasons.—76. The vague year and Sothic period.—77. Advantage of Egyptian year.—78. Greek year. —79. Meton and his cycle.—80. Origin of Golden Number.—81. Meton ridiculed by Aristophanes.—82. Near accordance of the lunar phases with the Metonic cycle.—83. Roman year.—84. Pontifical abuses.—85. Julian Calendar.—86. Bissextile years.

Chap. IV.—87. Year of confusion. —88. New arrangement of the months.—89. Mistake of the Pontiffs.—90. Leap-years.—91. Historical dates.—92. Day of the equinox.—93. What is the equinox? —94. The two equinoctial points. —95. Sidereal year.—96. Precession of the equinoxes.—97. Equinoctial year.—98. Civil year.—99. Difference between it and the Julian year.—100. Effect of this difference.—101. Cause of the reformation of the Calendar.—102. Discordance between the real and ecclesiastical equinox. — 103. Gregorian reform.—104. Gregorian Calendar.—105. Its compensating effect. — 106. Resistance to its adoption.—107. Dates of its adoption in different countries.—108. In England.—109. Its reception there.—110. Occasional agreement of the new and old styles.—111. Anecdotes relating to the change. —112. Russia adheres to the old style.—113. Commencement of the year.—114. Various in different countries. — 115. In England.—116. Old and new style in England.—117. Temporary inconvenience attending it.

THE ALMANACK.

Chap. I.—1. The almanack.— 2. The calendar.—3. The contents of an almanack — Predictions. — 4. Its prophetic character abused.—5. Saints' Days.—6. Date of the year.—7. Christan era.—8. Discrepancy between the reckoning of astronomers and chronologists.—9. When a century begins and ends. — 10. Commencement and duration of the seasons.—11. Beginning of the year.—12. Fixed and moveable feasts.—13. Easter. —14. Not dependent on the phases of the moon.—15. By what rule determined.—16. Rule not generally understood.—17. Equinox.—18. Ecclesiastical moon.—19. Age of the moon.—20. Full moon.—21. Error in the expression of the rule. — 22. Lunar cycle. — 23. Average length of civil and astronomical cycles agree. — 24. Fictitious moon never far distant from real moon. — 25. Golden Number.—26. Epact.—27. Used to determine the date of Easter.—28. Amount of separation of fictitious from real moon.—29. Limits of variation of date of Easter.—30. Earliest possible.—31. Latest possible.—32. Paschal moon.

Chap. II.—33. Paschal Moon sometimes gives a different Easter from real moon.—34. Occasion of public controversies.—35. Professor De Morgan points out error in Act of Parliament.—36. Other moveable feasts. — 37. Extract from De Morgan's Book of Almanacks.—38. Whit Sunday.—39. The Indiction. —40. Solar cycle.—41. To find the year of the current solar cycle. —42. Dominical or Sunday letter. —43. How affected by leap-year. —44. Sunday letter of the year 1 A.D.— 45. To find Sunday letter for any year. — 46. Eras. — 47. Julian Period.—48. Its commencement determined.—49. Its use in chronology.—50. Contents of the calendar. — 51. Aspect of the heavens.—52. Times of rising and setting of celestial bodies. — 53. Distortion produced by the atmosphere.—54. Other effects.—55. True and apparent sunrise.— 56. The sun seen before it rises. —57. Conventional meaning of the terms sunrise and sunset.—58. Refraction.—59. The Equinoxes. —60. Day and night rarely of the same length.—61. How modified by refraction.

CHAP. III.—62. Noon.—63. Clock time and sun time.—64. Declination of sun.—65. Tropics.—66. Solstices. — 67. Dog-days. — 68. Why midsummer is not the hottest season. — 69. Unequal intervals between the equinoxes.—70. Signs of the Zodiac.—71. Their designations.—72. Tropics of Cancer and Capricorn.—73. Change of position of constellations. — 74. Zodiac.— 75. Ecliptic.—76. Other contents of Almanack. — 77. Astronomical terms. — 78. Conjunction. — 79. Opposition. — 80. Quadratures. — —81. Morning and evening star.— 82. Further illustrations. — 83. Lunar changes.—84. When said to be gibbous.

CHAP. IV.—85. Full moon.—86. Last quarter.—87. Moon's age.— 88. Rate of motion variable.—89. Causes thereof.—90. "May Moon," "March Moon," &c.—91. Confusion arising from this form of expression. — 92. The epochs of chronology.—93. Anno Mundi.— 94. Era of Nabonassar.—95. The Hegira.

CLOCKS AND WATCHES.

CHAP. I.—1. General want of time measurers.—2. No natural measures for short intervals.—3. Approximative expedient by shadows. — 4. Sun-dials. — 5. Differently constructed for different places.—6. Earliest sun-dials.—7. Clepsydra, or water-clock.—8. Hour-glass.— 9. Mercurial time-gauge. — 10. Clocks — their chief parts. —11. Regulating power of the pendulum. —12. Uniform rate of vibration.— 13. Analysis of a vibration.—14. Experimental verification of isochronism. — 15. Moving power sustains the vibration.—16. Vibration not dependent on weight of pendulum.—17. Time of vibration varies with the length.—18. Analysis of motion of pendulous mass. — 19. How the pendulum governs the hands.—20. Produces intermitting motion.—21. Pendulum's motion maintained by moving power.

CHAP. II.—22. Action of pendulum on escapement wheel.—23. Rate of motion of hands produced by tooth and pinion work.—24. Method of making pinions. — 25. Mutual action of toothed wheels.—26. Wheel and pinion.—27. Bevelled and crown wheels.—28. Weight applied as a moving power.—29. Why hands not turned back when clock is wound up.—30. Mainspring.—31. Its power variable.— 32. The fusee.—33. Balance-wheel. —34. Its vibrations uniform.—35. General explanation of a watch.— 36. Of a clock moved by a weight. —37. Method of regulating the rate.

CHAP. III.—38. Method of regulating a balance-wheel.—39. Recoil escapement.—40. Cylindrical escapement.—41. Duplex.—42. Lever.—43. Detached.—44. Maintaining power of a clock moved by a weight.—45. Of a watch moved by a main-spring.—46. Weight of mainspring and pendulum and balance-wheel variously combined.—47. Watches and chronometers.—48. Marine chronometers.—49. Stationary chronometers.—50. Striking apparatus.

SPECTACLES.

1. Their general utility.—2. Should therefore be generally understood.—3. Vision.—4. Blindness.—5. Defective sight.—6. Long and short sight.—7. Remedy.—8. Spectacles.—9. Effect of convex lenses.—10. Of concave lenses.—11. Focal length of a lens.—12. Varies with distance of object.—13. Peculiarities of vision in short sight explained.—14. In long sight.—15. The mounting of Spectacles.—16. Periscopic Spectacles.—17. Both eyes have not always the same power of vision.—18. Ophthalmometer.—19. Application in selecting glasses.—20. Curious defects of vision.

COLOUR.

CHAP. I.—1. Colours depend upon reflected lights.—2. Bodies luminous and non-luminous.—3. Luminaries.—4. Non-luminous bodies.—5. Transparency and opacity.—6. Transparency never perfect.—7. Opacity never perfect.—8. Bodies rendered visible by reflected light.—9. Irregular reflection.—10. Reflecting powers vary.—11. The blackest body reflects some light.—12. Irregular reflection necessary to vision.—13. Use of the atmosphere in diffusing light.

CHAP. II.—14. Diffusion of light by all visible objects.—15. Decomposition of light by visible objects.—16. Experimental proof of the composition of light.—17. The prismatic spectrum.—18. The composition of solar light.—19. The recomposition of light by prism and concave reflector.—20. The same by prism and lens.—21. The same with artificial colours.—22. Light of the same colour may have different refrangibilities.—23. Colours produced by combining different rays of the spectrum.—24. Complementary colours.—25. Colours of natural bodies generally compound.—26. Method of observing the spectrum by direct vision.—27. Why objects seen through prism are fringed with colours.—28. The prismatic colours, not all simple.—29. Sir D. Brewster's analysis of the spectrum.

THE KALEIDOSCOPE.

1. Origin of the name.—2. Structure of the instrument.—3. Its optical effect.—4. Varieties of its form.—5. Its occasional use in the arts.—6. Another optical toy depending on two reflections.

CONTENTS.

PUMPS.

1. Earliest methods of raising water.—2. Bucket in a well.—3. By windlass and rope.—4. By two buckets balanced over a pulley.—5. Method of working these by animal power.—6. The rope in this case balances itself.—7. The lifting pump.—8. Double lifting pump worked by animal power.—9. Various forms of valves.—10. Cluck valves.—11. Conical spindle valves.—12. Ball valves.—13. The suction pump.—14. Analysis of its action.—15. Forcing pump.—16. Same with air vessel.—17. Same with solid plunger.—18. Double action forcing pump.—19. Garden watering pumps.—20. Fire-engine.—21. Chain pump.—22. Drainage of mines.

ERRATUM IN "COMMON THINGS—THE ALMANACK."

Section 73, line 26, *for* "February" *read* "April."

COMMON THINGS.

AIR.

1. Air most necessary to existence.—2. Respiration.—3. Fresh air necessary.—4. Air is material.—5. Its weight and momentum.—6. How weighed.—7. The atmosphere.—8. Its pressure.—9. Why bodies not crushed by it.—10. Illustrated by a cupping-glass.—11. Compressibility.—12. Elasticity.—13. Elastic pressure.—14. Varies with the density.—15. Strata of atmosphere near the surface of the earth and at greater elevations.—Diminished pressure at great elevations. —16. Anciently supposed to be an element.—17. Air a compound.—18. Gases.—19. Proportion of the constituents of air.—20. Azote or nitrogen.—21. Oxygen gas.—22. Combustion.—23. Its products.—24. Carbonic acid.—25. Unfit for respiration.—26. Impure air produced in warming and lighting.—27. Ventilation of public buildings.

—28. Carbonic acid in effervescing liquors.—29. Is generated in all spontaneous changes of dead matter.—30. Choke-damp.—31. Is diffused through the atmosphere.—32. Evolved in respiration.—33. Vital air.—34. Air poisoned in crowded rooms.—35. Necessity of ventilation.—36. Air not absolutely transparent or colourless.

1. Of all common things, air is the most common. No space or place is accessible to us that is not filled with it. It is of all material wants that which is most incessantly indispensable to our existence. Food is an occasional want, an intermitting supply is all that is needed. Clothing may in certain cases be dispensed with, and habit may inure us to a deficiency of it. The want of warmth must be extreme to become fatal. But the privation of air, even for a brief interval, is attended with instant and certain death.

Unlike other natural wants, our consumption of air is not voluntary. The action of the lungs is like the oscillations of a pendulum. It is incessant, sleeping or waking, in sickness or in health; sitting, standing, or moving, it is maintained with a regularity and continuity quite independent of the will. Its suspension is the suspension of life.

Must we not then be prompted by a natural and irresistible curiosity to obtain some acquaintance with a physical agent so universal, so omnipresent, and so indispensable to our vitality?

2. Air is the transparent, colourless, invisible, light, and attenuated fluid with which we are always surrounded. It is drawn into our lungs by the action called suction, and after remaining a moment there, is forced out through the mouth and nose by the muscular compression of the chest. This alternate action, by which the air enters and leaves the lungs, is called respiration. During the moment it remains in the lungs, it undergoes a certain change, which we shall presently explain, in consequence of which, when expired, it is not the same as that which was inspired. The effect produced on the blood by this change is essential to the maintenance of life.

The air which, thus changed, is expired, is unfit for respiration. If, therefore, the same air be taken several times successively into the lungs, death must ensue.

3. The air around us, therefore, requires to be continually changed, that which we expire being carried away and replaced by fresh and pure air.

4. The apparent lightness of air, the freedom with which we move through it, and its invisibility, led the ancients to imagine that it was unsubstantial and immaterial, and hence the disembodied souls of the dead came to be called *spirits*, from the word *spiritus*, which signifies *air*.

5. It is a great mistake, however, to imagine that air is destitute of weight, that quality which is inseparable from whatever is material. Light it undoubtedly is, but only by comparison. Bulk for bulk, it is lighter than stone, earth, or water, or any other substance in the solid or liquid state. But light as it is, it has a certain definite weight, and a quantity of it can be assigned which will weigh many tons. The pressure produced by its weight is under certain assignable circumstances quite enormous, and when it is moved with a certain velocity its force is so irresistible that trees are torn by it from their roots, the most solid buildings overturned and reduced to ruins, and devastation spread over vast tracts of country.

Nothing can be easier than to show practically that air has weight, and what that weight is.

6. If a glass flask, having the capacity of a cubic foot, be provided with a proper neck, furnished with a stop-cock, we shall be able, by means of a well-constructed syringe, to extract from it the air which it contains, and by closing the stop-cock, and detaching the syringe, we shall have the flask void of air. Let it be weighed in that state in a good balance. Let the stop-cock be then opened so as to admit the air to fill the flask, and let it then be weighed again. It will be found to weigh 1·291 oz. or 564·8 grains more than it did when void of air.

It follows therefore that a cubic foot of air weighs 564·8 grains.

Since the weight of a cubic foot of water is 997·125 oz., it follows that, bulk for bulk, water is heavier than air in the proportion of 997·125 to 1·291, that is, of 772½ to 1.

Since thirty-six cubic feet of water weighs a ton, it follows that 772½ times thirty-six cubic feet of air also weighs a ton.

It appears, therefore, that 27810 cubic feet of air will weigh a ton.

7. When it is considered that the mass of air which taken collectively is called the ATMOSPHERE, extends above us to the height of more than fifty miles, it will easily be imagined that the weight with which it presses on the surface of every object exposed to it, must be very considerable. If, for example, we take a square inch of level surface, it is clear that that square inch must bear the weight of a column of air extending from that surface to the top of the atmosphere. It has been ascertained by experiments, susceptible of the greatest precision, (which we shall explain on another occasion) that this pressure or weight amounts to about 15lbs., and that it is subject, from time to time, to a variation not exceeding three quarters of a pound.

8. It is a well known property of fluids, that any pressure which

they exert, acts equally in all possible directions. Thus, if any body be let down into the sea, the weight of the water, which is above it, will press equally on its top, bottom, and sides. It is very easy to demonstrate this by a simple experiment.

Let several empty bottles be carefully corked, and being loaded with weights so as to sink in the water, the neck of one being presented upwards, that of another downwards, another horizontal, and the others oblique in various degrees, it will be found that when they have been sunk to a certain depth, the corks will be all forced into the bottles by the pressure of the surrounding water, with which the bottles will be immediately filled, and this will take place equally, and at the same time, with all the bottles, in whatever directions the corks may be presented to the water.

It is evident, therefore, that the pressure produced by the weight of the incumbent column of water at any given depth is equally propagated in all directions, and that a body, a fish for example, or the body of a diver, sustains that pressure, not downwards only, or on the upper surface of the body as might be at first imagined, but equally on the under surface, the sides, and, in a word, on every part of the body in contact with the water.

Now this equal transmission or propagation of pressure in all directions, is not an exclusive property of water, but is common to all substances whatever in the fluid state. Air possesses fluidity in even a greater degree, if possible, than water, being more freely mobile, and air accordingly transmits freely and without diminution in all directions whatever any pressure which it receives. The stratum of air in which we live is under the pressure, as has just been stated, of the incumbent column of air extending upwards to the limits of the atmosphere, this pressure amounting to 15 lbs. on each square inch. A body, therefore, exposed to the contact of this air is subject at all parts of its surface, upper, under, and lateral, to this pressure; and the total amount of the pressure by which it is affected will be expressed in pounds weight by the number obtained by multiplying the number of square inches in its entire surface by 15.

The body of a man of average size has a surface of about 2000 square inches. The total pressure which it sustains from the surrounding air is therefore 15 × 2000, or 30000 lbs., or nearly fourteen tons!

9. It may seem wonderful that a force so enormous, acting on all parts of the surface of the body, should not crush it and actually destroy its delicately constructed organs. This, however, is prevented by the perfect equilibrium of pressure outwards and inwards, produced by the property of fluids just explained, in

virtue of which they transmit freely, and undiminished, the pressure in all directions. The fluids which fill the entire vascular system are exposed, as well as the surface of the body, to the pressure of the atmosphere, which enters the lungs and all the cavities and open parts of the organs. These fluids transmit that pressure to all the inner parts of the body, so that the skin and integuments are pressed by them outwards by a force exactly equal to that with which the air presses the external surface of the skin inwards. These outward and inward pressures are necessarily always equal, because, in fact, they are one and the same pressure, *i.e.*, that of the air, the pressure on the external surface acting inwards, being the immediate action of the air, and the pressure of the internal fluids acting outwards being the same pressure of the air transmitted by those fluids to the inside of the skin and integuments.

10. That this outward pressure, transmitted by the fluids which fill the organs under the skin, is really at all times in operation, and that it is only counteracted by the immediate pressure of the external air upon the skin, is rendered conspicuously manifest in the well-known surgical operation of cupping. In that process the open mouth of the cupping-glass being pressed upon the skin so as to exclude all communication with the external air, the air within the cup is withdrawn, or partially withdrawn, by means of a syringe attached to the glass. The moment the skin within the glass is relieved from even a small part of the pressure of the external air by this means, the outward pressure of the fluids under the skin begins to take effect, being no longer resisted; it swells up the skin within the glass, and when the skin thus dilated is punctured with the lancet, the blood is propelled from it by the force of the pressure of the fluids under the skin acting outwards.

11. The free transmission of pressure in all directions is a property which air has in common with water and other liquids. It has, however, another quality eminently characteristic, which is not found in liquids, or any other form of matter. The property we refer to is unlimited compressibility.

Let a tube A B (fig. 1) be provided, open at one end A, and closed at the other B, and let a solid plug P be made to fit it air-tight. Let an opening, governed by a stop-cock, be provided at C. When the plug is inserted at A, the air inclosed by it in the tube will be in its natural state, provided the stop-cock be open, and the plug will be pressed upon it by the amount of the atmospheric pressure. If we suppose the plug to have the magnitude of a square inch, this pressure will be fifteen pounds.

The stop-cock C being closed, let the plug P be pressed down with a force of fifteen pounds. If the tube were filled with water instead of air, the plug would in that case maintain its position, for the water would not yield in any degree to the pressure. But the case is quite otherwise with air. The moment the pressure is applied, the plug will descend in the tube, squeezing or compressing the air into a less space, and it will continue to descend until the air is compressed half its original bulk. There the compression will cease, and the plug will remain at half its original distance from the bottom B of the tube, as in fig. 2.

Fig. 1.

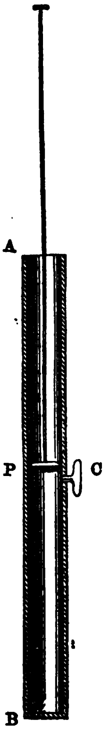
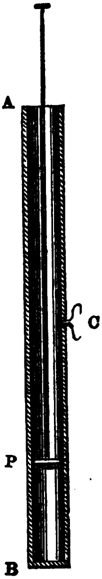


Fig. 2.



Thus, if the original height of the plug P above the bottom of the tube were twelve inches, the plug being pressed downwards only by the atmospheric pressure, that is, by 15 lbs., its height, when pressed by 15 lbs. more, that is, by 30 lbs. in all, will be six inches. The air, which is compressed into twelve inches by 15 lbs., is therefore compressed into six inches by 30 lbs., the volume of the air being diminished in the exact proportion in which this compressing force is augmented.

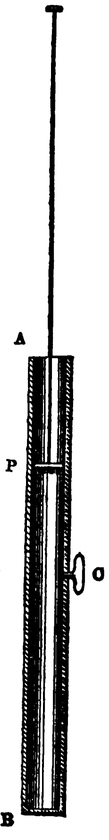
This experiment may be carried farther with a like result. If the piston be forced down with a weight of 30 lbs., in addition to the atmospheric pressure, which is 15 lbs., the whole compressing force will be 45 lbs. In this case, the compressing force being augmented in the proportion of three to one, the space into which the air is compressed will be decreased in the same ratio, and the plug P will descend to four inches from the bottom B.

In general, therefore, the space into which air will be squeezed by any force will be less in exactly the proportion in which the compressing force is increased, it being well understood, nevertheless, that the original pressure of the external air, amounting to 15 lbs. per square inch, is to be included in the compressing force.

This property of unlimited and uniformly regular compressibility is one of the essential and characteristic properties of air, being one in which no other form of matter participates. Liquids are in general, for all practical purposes, absolutely incompressible. Some solids are compressible in a certain slight degree, but not at all in the general and regular way in which air is compressible.

12. Air has another characteristic and highly important quality, called ELASTICITY, which, like its compressibility, is unlimited and uniform.

Fig. 3.



Let us suppose that the plug P in the tube A B, fig. 1, instead of being pressed down, is drawn upwards, the tube being long enough to allow it all the necessary play, as in fig. 3. If, in that case, water had filled the tube under the plug, a void space would remain between the surface of the water and the plug. In short, the elevation of the plug would be followed by no sensible change in the space occupied by the water. But when the tube contains air, the result is quite otherwise. In that case, when the plug is drawn upwards, the air which before filled the tube between the plug and the bottom now expands, and swells so as still to fill the increased space left open to it by the elevation of the plug, and this expansion will go on without any practical limit to whatever height the plug may be elevated.

This capability of swelling without limit into augmented dimensions when relieved from the conditions which confine it is called ELASTICITY. Like COMPRESSIBILITY, it is a characteristic property in which no other form of matter participates. Liquids are for all practical purposes inelastic. Some solid bodies possess a certain elasticity, but not at all identical in its character or laws with the elasticity of air above described.

13. It has been explained that air in its common state exercises a pressure of 15 lbs. on each square inch of surface with which it is in contact. It exercises this pressure equally whether it is in communication with the external atmosphere or not. In the case of the tube A B and plug P, the air in the tube, before the introduction of the plug, pressed on the surface of the tube with a force of 15 lbs. per square inch, because it sustained that pressure from the incumbent weight of the atmosphere, and transmitted that pressure freely and undiminished to the inner surface of the tube. But when the plug is introduced, all communication with the external air is cut off, and nevertheless the included air still presses on the surface of the tube with the same force. As this pressure cannot arise from the incumbent weight of the external air, all communication with which is intercepted by the piston, it is due altogether to the elasticity of the air confined within the tube.

The piston inserted in the tube in this case is therefore subject to the action of two equal forces. The WEIGHT of the external air presses it *downwards* with a force of 15 lbs., and the ELASTICITY of the air confined within the tube presses it *upwards* with an equal force of 15 lbs. The piston is thus held in equilibrium, having no tendency either to rise or fall in the tube.

Indeed, the very fact that the piston inserted in the tube A B has no tendency to descend into it, and to compress the air under it, although it is urged downwards by the air above it with a force of 15 lbs., proves that the air below it must urge it upwards by a force exactly equal; since, if it were urged upwards by any less force, it would be pressed down by this excess of the force of the external air, and if it were urged upwards by any greater force than 15 lbs., it would ascend with the excess of this upward force.

Air, therefore, in its natural and usual state, has an elastic force of 15 lbs. per square inch, so that when it is shut up in any vessel or other envelope, and cut off from all communication with the external air, it will press on every square inch of the inner surface of such envelope with a force of 15 lbs.

14. This elastic force increases in the same proportion as the space in which the air is confined is diminished by compression, and it decreases in the same proportion as the space into which it is allowed to expand is increased. Thus, if we suppose that when the air fills twelve inches of the tube A B, fig. 1, it has an elastic force of 15 lbs., it will have an elastic force of 30 lbs. when it fills six inches of the tube; 45 lbs. when it fills four inches; 60 lbs. when it fills three inches, and so on. And in like manner when it is allowed to expand so as to fill twenty-four inches, its elastic force will be reduced to 7½ lbs.; when it expands to thirty-six inches, the elastic force will only be 5 lbs., and so on.

15. The stratum of air which rests on the surface of the earth, and in which the organised tribes that inhabit the earth live, derives its pressure, elasticity, and density from the weight of the whole mass of the atmosphere which rests upon it. It must, therefore, be evident, that if we ascend to greater elevations, leaving below us a certain stratum of the atmosphere, and having above us a proportionally less quantity of air, the weight of the incumbent air being less, the pressure, elasticity, and density of the stratum which surrounds us will be proportionally less. And we find this actually to be the case. At great heights on mountain chains, such as the Pyrenees or the Alps, the air is very sensibly rarefied. It is lighter, and exercises a much less pressure. In like manner, persons who ascend to great elevations in balloons find much inconvenience from the thinness of the air. The fluids confined within the body are much less resisted, certain organs become dilated, and the effect of a cupping-glass is occasionally produced, attended with bleeding at the nose, and singing in the ears.

16. The ancients imagined that air was a simple substance which entered more or less into the composition of bodies in general, and hence they called it one of the elements; the others being in their theory of physics, water, earth, and fire. Better informed now, we know that neither air, water, nor earth, are simple or elementary substances, and that fire is not a substance at all, but a physical effect due to the sudden and large production of heat which attends the chemical combination of certain substances. Thus the ancient elements are not elements at all.

But to return to air, the more immediate object of our attention at present.

17. Air—meaning by that term the air of the atmosphere, the air we breathe, the air through which we behold the firmament, the air whose currents carry our commerce over the ocean from land to land—is a compound or mixture made up of two extremely different kinds of air.

18. As there are many sorts of air having extremely different qualities and properties, although they are alike in appearance, being all invisible, transparent, colourless, light, compressible, and elastic, it has been found convenient to call them by the general name *gas* (derived from the Saxon word *gast*), and to limit the application of the term "air" to that particular compound or mixture of gases which constitutes the atmosphere.

19. The erroneous notion that air was a simple and elementary substance prevailed until the close of the last century, when Lavoisier, the celebrated French philosopher, who was one of the most illustrious of the founders of modern chemistry, showed that it was a mixture of two different gases in definite proportions, called oxygen, and azote or nitrogen.

A hundred cubic inches of air is a mixture consisting of 80 cubic inches of azote, and 20 of oxygen. The result of the most exact analyses differs from this proportion by a minute fraction, which, though not unimportant in certain respects, need not here embarrass the reader, who will do well to fix in his memory this proportion of 80 to 20.

There are many ways in which this constitution of atmospheric air may be made manifest, some of which, however, involve principles which would not be comprehended without a more extensive knowledge of chemistry than is expected from our readers in general. The following demonstration will, however, it is hoped, be understood without difficulty.

Let 100 cubic inches of common air, and 40 cubic inches of the gas called hydrogen, be introduced into a closed flask. If an electric spark be transmitted through this mixture, which may be easily done, an explosion will take place with a considerable development of heat. When the flask has been cooled, and its contents examined, it will be found to contain eighty cubic inches of azote and a quantity of water, whose weight is exactly equal to the combined weights of twenty cubic inches of oxygen and forty cubic inches of hydrogen.

The inference from this experiment is, that, under the influence of the electric spark, one of the constituents of the air has entered into combination with the hydrogen, and that their compound is water; and since the air has lost twenty cubic inches, it follows that this portion of it is a gas which has the property of combining with twice its own measure of hydrogen, and thus forming water. The gas which possesses this property is called oxygen.

The experiment here described is attended with two results, both of which have high importance. It proves first that 100 cubic inches of common air consists of eighty cubic inches of azote, and twenty of oxygen; and, secondly, that twenty cubic inches of oxygen mixed with forty of hydrogen will be converted into water by passing through them the electric spark.

It now remains to explain the chief properties of the two gases, by the mixture of which, in the proportion of eighty to twenty, or four to one, common air is formed.

20. Azote, or nitrogen, which thus forms four-fifths of the air we respire, is characterised by negative rather than positive qualities. It has neither colour, taste, nor odour. A candle or lamp is immediately extinguished when introduced into it. No animal which requires respiration can live in it.

Although this inability to support life by respiration is not peculiar to this particular gas, it has nevertheless given to it the name azote, from two Greek words signifying the negation of life.

This gas is not inflammable.

The destructive influence of this gas on animal life does not arise from any poisonous or injurious quality in the gas itself, but altogether from the absence of oxygen.

This gas, when compressed by the same force, is very little different in weight from common air. A hundred cubic inches of it weigh $30\frac{1}{6}$ grains, while 100 cubic inches of common air weigh 31 grains.

21. The other constituent of atmospheric air, called oxygen, is characterised by many very remarkable properties.

Like azote, this gas has neither colour, taste, nor odour. Bulk for bulk, and under equal pressure, it is a little heavier than common air, 100 cubic inches weighing $34\frac{1}{5}$ grains.

The properties which are most conspicuously characteristic of this gas are those which relate to combustion and respiration.

22. Combustion, or burning, is a phenomenon which consists of

the large and sudden evolution of heat and light arising from the combination of a class of bodies, called combustibles, with oxygen.

If a piece of charcoal be heated to redness, it will immediately begin to combine chemically with the oxygen of the atmosphere. A great heat and a vivid light are produced in this combination, and the product of it is a compound gas, composed of oxygen and carbon, and called carbonic acid.

In like manner, if sulphur or phosphorus be similarly heated, similar effects will ensue.

But since it is evident that these phenomena thus produced in common air arise exclusively from the presence of oxygen, which nevertheless forms only a fifth part of that air, it may naturally be inferred that if the same combustibles were placed in an atmosphere containing a greater portion of oxygen, and still more if they were placed in an atmosphere of pure oxygen, the phenomena would be far more vivid.

And this is accordingly found to be the case.

All substances, which are capable of burning in common air, burn with far greater intensity and splendour in an atmosphere of pure oxygen. A piece of wood on which the least spark of light is visible, which would be spontaneously extinguished in common air, will burst into flame the moment it is plunged in a jar of pure oxygen. A piece of charcoal, heated to redness at its point, will in like circumstances enter into vivid combustion, emitting the most brilliant scintillations, until it altogether disappears. Phosphorus similarly treated burns with a light too splendid to be looked at without pain. If the extremity of a coil of steel wire be heated to redness, and plunged in such a jar, the wire will be rapidly burnt, emitting in like manner streams of brilliant sparks.

These substances severally disappear in the process of combustion, and before science had attained to its present state of advancement it was supposed that they were destroyed. It is now known that the destruction of matter, in any form, and by any natural process, is as impossible as its creation. It is a physical maxim of high generality and undoubted truth that nothing but the immediate operation of the Divine will can either augment or diminish the quantity of matter composing the world. Whenever ponderable matter, therefore, seems to disappear, we are called upon to trace it, to discover its hiding-place, and to explain the nature and the cause of the change which produces its disappearance. In the present case nothing is easier.

23. Let us suppose, for example, that a piece of lighted charcoal of sufficient magnitude is plunged in a closed glass jar filled with

pure oxygen gas. The vivid combustion of the charcoal will take place, and will be continued for a certain time, when it will cease, becoming continually less vivid until it is extinguished. If the gas now contained in the jar be examined by the usual chemical test, it will be found that it is no longer oxygen. A taper plunged in it will be instantly extinguished. An animal placed in it will die. Its weight will be greater than that which it had previously to the experiment, and if the unburnt residue of the charcoal be weighed it will be found to have lost precisely the weight which the gas has gained.

In a word, the oxygen gas has been converted into another and heavier gas, called carbonic acid, and this has been accomplished by a portion of the charcoal entering into chemical combination with it, that combination being attended with the evolution of heat and light, which characterises the phenomenon of combustion or burning.

24. Now it is most desirable to become familiar with the character and properties of this gas, for it plays a most important part in numberless processes and phenomena natural and artificial, which we encounter daily and hourly in the common experience of life.

Like all other gases, carbonic acid in its ordinary state is invisible, colourless, compressible, and elastic. It has a pungent smell and acidulous taste. If reduced to the temperature of melting ice and compressed with a force of 36 atmospheres, that is of 36 × 15, or 540 lbs. per square inch, it is reduced to a liquid, and when reduced to 180° below zero of Fahrenheit's thermometer, it is frozen and becomes solid.

25. This gas is altogether unfit for respiration. When breathed pure it produces a violent spasm of the organ of the throat called the glottis, which prevents the gas from entering the lungs. If, however, it be mixed with so much common air as to prevent it from producing this spasm, it may enter the lungs, and in that case it acts on the system as a narcotic poison.

26. All substances used for warming rooms, such as coal, coke and wood, and all such as are used for lighting them, such as oil, tallow, wax, consist chiefly of carbon combined in small proportions with other constituents. The chief product of the combustion of all such substances is therefore carbonic acid. When coal, or other fuel, is burnt in a grate or stove, the carbonic acid is carried away by the chimney or flue, and therefore does not pollute the air of the room. But this is not the case with the carbonic acid produced by the candles and lamps used to illuminate the room. All the carbonic acid produced by them mixes with the atmosphere of the room and poisons it to

a proportionate degree. As this gas is evolved in the flame of the lamps and candles in a heated and highly expanded state, it will ascend to the ceiling of the room, and will float in a stratum there for a certain time. If means are not provided for its escape it will soon descend into, mix with, and poison the air of the room, and render it injurious to the health of those who breathe it.

27. In theatres and other large buildings, which are sometimes illuminated by a central chandelier suspended from the ceiling, an opening is provided over the chandelier, which permits the escape of the carbonic acid, exactly as the chimney of a fireplace or the flue of a stove receives that which is produced by the combustion of the fuel. In all cases whatever, the healthiness of apartments would be greatly increased if similar openings were provided for the escape of the carbonic acid produced by lamps, candles, and other causes.

28. The effervescence of soda water, champagne, ale, beer, and other similar drinks is produced by carbonic acid, which is fixed in them, and suddenly liberated when relieved from the confining pressure by the withdrawal of the cork. The agreeable pungency of these liquors is in a great degree due to the presence of this carbonic acid, which being allowed to escape by exposure in the air, or by leaving the bottle uncorked, the drink becomes stale and flat.

Water commonly contains more or less carbonic acid fixed in it. This being expelled by the process of boiling, cold boiled water acquires a peculiarly insipid taste, owing to the absence of the acid gas.

It appears that the reception of carbonic acid gas into the stomach is not attended with the same deleterious effects as are produced by its introduction into the lungs. There are few forms of food or drink which do not include more or less of it.

In general, fermentation is attended with the evolution of carbonic acid. The gas ejected from dyspeptic stomachs affected by flatulency is carbonic acid.

29. This gas is abundantly generated in all the spontaneous changes which attend the corruption of dead animal and vegetable matter. In autumn, after the fall of the leaf in woods, forests, and gardens, and in all places where dead leaves are allowed to accumulate, the air is more or less impregnated with carbonic acid, which, by reason of its weight, remains long collected in the lower strata of the air, rendering it unhealthy.

30. This gas is often collected and retained in the bottom of old wells, where it is known under the name of *choke-damp*. An animal which descends in such a well dies.

It sometimes issues from the earth, being evolved in some subterraneous process. Examples of this are presented in the case of the celebrated Grotto del Cane in Italy, and at Pyrmont, in Westphalia. The former place takes its name from the cruel and now useless experiment of showing that a dog let down into it dies.

31. Carbonic acid is so much heavier than air, that it may be decanted like a liquid from one vessel to another. It is, however, a mistake to suppose that in consequence of its relative weight, it will permanently sink to the lowest strata of the atmosphere on which it happens to be placed, on the same principle that water would sink to the bottom of oil. Gases in general are subject to a physical law, in virtue of which they mingle one with another when they are in contact, and become at length uniformly diffused through each other, notwithstanding these differences of weight.

A small proportion of this gas is always diffused through the atmosphere, being the produce of innumerable natural processes which take place on the surface of the earth. This is not to be regarded, however, as a constituent of common air, any more than the mud of the Mississippi or the Tiber, or the salt of the ocean, is to be considered as a constituent part of pure water.

32. Carbonic acid is evolved in large quantities by respiration. The oxygen, which forms one-fifth part of the common air which is inspired in respiration, is absorbed by the blood before it enters the arterial system, and the same blood on issuing from the venous system dismisses a corresponding quantity of carbonic acid, which is expired at the mouth and nostrils. Thus, while the air inspired is a mixture of azote and oxygen, the air expired is a mixture of azote and carbonic acid.

The effect, therefore, of respiration on the surrounding air is precisely the same as that of a lamp or candle. In both cases the oxygen constituent disappears, and is replaced by carbonic acid.

It is evident, therefore, that it is the oxygen constituent of common air which is the means of supporting animal life by a specific effect which it produces upon the blood which absorbs it, and which carries it through the arterial and venous systems, where it is converted into carbonic acid, and discharges a variety of functions necessary to the maintenance of life.

33. It is for this reason that oxygen is often called VITAL AIR.

34. In apartments or buildings where persons are crowded together in large numbers, more especially when they are illuminated by artificial light, there is therefore an enormous and rapid production of this noxious gas, as well by respiration as by the lamps, candles, or gas-burners used for illumination.

Although in large public buildings which are habitually thus filled, proper means of ventilation are often provided, this is not the case in general in private residences, where such assemblies are only occasional. Hence it happens that large parties, balls, and other social entertainments given in private houses are extremely injurious to the health. Multitudes are crowded together in brilliantly-lighted rooms. The respiration, the exhalation from the skin produced by an elevated temperature and by the exercise of dancing, and the combustion of vast numbers of candles, lamps, and gas-lights, evolve carbonic acid in large quantities, which, having no means of escape, accumulates until the company becomes painfully sensible of its ill-effects on respiration. Relief is then sought by opening one or more windows or doors, by which currents of fresh air are let in, and the foul air drawn out. If the air thus admitted were of a proper temperature, this palliative of the evil might be admitted to be partially efficient; but the air thus introduced is usually of a temperature from twenty to forty degrees lower than that of the room. The persons exposed to these sudden cold currents, more especially females, having their highly heated skins and open pores extensively uncovered, receive a chill, by which the integument contracting drives back into the blood the fluids which ought to have been permitted to escape by cuticular transpiration. Hence arise numberless diseases, rheumatisms, colds, fevers, and in more cases than is ever known or acknowledged, premature and ultimate death.

35. It will be apparent from these considerations how much it behoves architects, builders, and proprietors to provide proper expedients in the erection of private residences for the efficient ventilation of rooms.

36. We have stated that air is colourless and transparent, and this is practically true not only of common air, but of gases generally, when they are exhibited in such moderate quantities as are usually submitted to observation or experiment. Strictly speaking, however, air is not absolutely transparent or absolutely free from colour.

When a fluid is very faintly coloured, its peculiar hue is only perceptible when a considerable depth or thickness of it is submitted to view. If a tapering glass, such as those used for champagne, be filled with pale sherry or other liquor of a like colour, the peculiar colour of the liquid will be distinctly enough perceived at the top of the glass, when the eye views a certain thickness of it; but the colour becomes fainter and fainter towards the point of the cone, where it is scarcely perceptible. If a glass tube of small bore be dipped in the liquid, and, the finger being applied at the upper end to stop it, it be raised, the liquid which will be suspended in the tube will appear as transparent and colourless as water. It cannot be doubted, nevertheless, that the liquid in the tube has the same colour as the liquid in the glass. The colour is not perceived only because the quantity in the tube is too small to reflect sufficient colour to produce a sensible effect on the eye.

The atmosphere is in the same circumstances. The colour reflected even from a considerable volume of it is too faint to be perceptible. Thus the air which fills a room, or which intervenes between the eye and the buildings, trees, and other objects around us, appears quite transparent and colourless, and we see all such objects distinctly through it in their proper colours. But when, in the daytime, we look up through fifty or sixty miles height of air, illuminated by solar light, we find that a strong and decided tint of blue is perceived. This azure, which in the absence of clouds forms the celestial vault, belongs not to anything which occupies the regions of the universe in which the heavenly bodies are placed, but to the vast mass of air through which these bodies are seen.

To perceive this peculiar colour of air, however, it is not necessary that so vast a mass should be presented to the eye. Distant mountains appear bluish, not because that is their colour, but because it is the hue of the aërial medium through which we look at them. As we approach them, the quantity of the intervening air being diminished, this bluish tint is no longer perceived, and they appear with their proper colours.

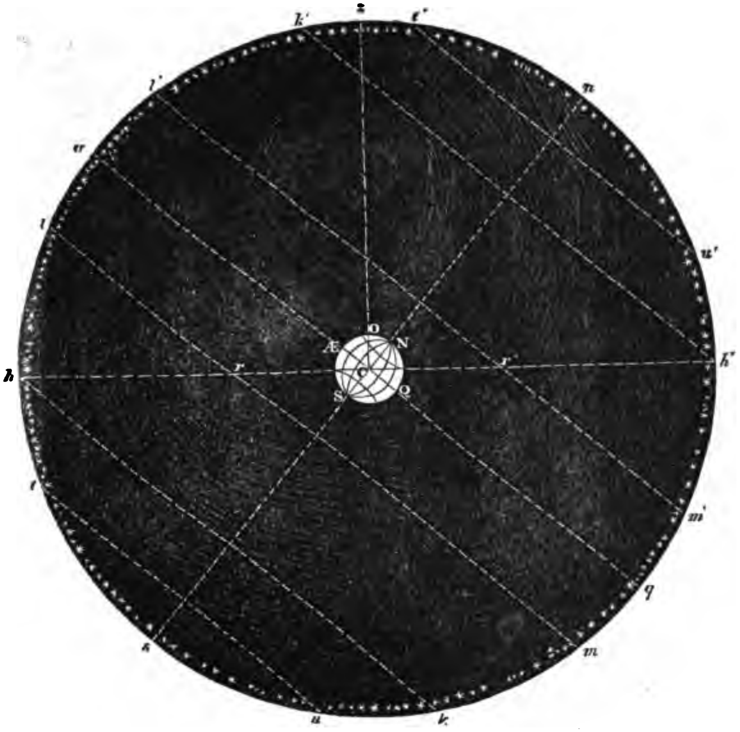


Fig. 2.

COMMON THINGS.

THE EARTH.

1. Difficulty of observing the earth as a whole.—2. It appears at first an indefinite flat surface.—3. This disproved by travelling round it.—4. Proof of the curvature of its surface by observation of distant objects at sea.—5. By the Earth's shadow projected on the Moon.—6. Inequalities of surface, such as mountains and valleys, insignificant.—7. Magnitude of Earth, how ascertained.—8. Length of a degree of latitude.—9-10. Illustrations of the Earth's magnitude.—11. Is the Earth at rest?—12. Apparent motion of the firmament.—13. Origin of the word "Universe."—14. This apparent motion may not be real—may arise from the rotation of the Earth.—15. How such a rotation would produce it.—16. Poles.—17. Equator.—18. Hemispheres.—19.

Meridians.—20. Which of the two rotations is the more probable?—21. Rotation of the universe impossible.—22. Simplicity of the supposed rotation of the globe.—23. Direct proofs of this motion.—24. Foucault's experiment.—25. Its analogy to the planets.—26. Conclusion as to the globular form of the earth requires modification.—27. All human knowledge tentative and approximative.—28. Rotation not compatible with the exact globular form.—29. Centrifugal force of the Earth's rotation.—30. The globe rotating would assume the form of an oblate spheroid.—31. The degree of ellipticity would vary with the velocity of rotation.—32. Experimental illustration.—33. Ellipticity corresponding to the diurnal rotation.—34. How these circumstances affect the actual state of the Earth.—35. Form of a terrestrial meridian.—36. Dimensions of the terrestrial spheroid.—37. Its departure from an exact globe very small.—38. Its density and mass.—39. Determined by Cavendish and Maskelyne.—40. Its total weight.

1. LOCKE somewhere observes, with his usual felicity of illustration, that the "mind, like the eye, while it makes us see and perceive all other things, can never turn its view with advantage upon itself." We encounter something similar to this in our researches through the universe; for of all the objects which compose it, one of the most difficult of which to obtain a complete and accurate knowledge is the planet which we inhabit. The cause of this is our proximity to it, and intimate connexion with it. We are confined upon its surface, from which we cannot separate ourselves. We cannot obtain a bird's-eye view of it, nor at any one time behold more than an insignificant portion of its surface. We have the same difficulty in obtaining an acquaintance with it that a microscopic animalcule would have in acquiring a perfect knowledge of the form and dimensions of a terrestrial globe twelve inches in diameter, on the surface of which it creeps.

Still, by a variety of indirect methods supplied by the ingenuity of scientific research, we have been enabled to ascertain its form, dimensions, and physical constitution, with a considerable degree of accuracy.

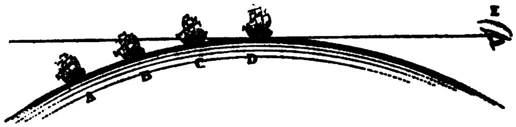
2. The first impression produced upon the eye of an observer, who has not carried his inquiries further, is, that the surface of the earth is a flat plane, interrupted only by the inequalities of the land. A little careful observation, however, upon the many phenomena which are easily accessible to every observer, will correct this erroneous impression.

3. It is well known that if a voyage were made upon the earth, continually preserving one and the same direction, or doing so as nearly as circumstances will permit, we should at length arrive at the place from which we departed. If the earth were an indefinite plane, this could not happen. It is evident, then, that whatever be the exact form of the earth, it is a body which is on

every side limited, and one which must therefore have such a surface that a traveller or navigator can completely surround it in one continuous course.

4. Let us see, however, whether we may not obtain evidence more distinct as to its form. If we stand on the deck of a ship at sea, and out of sight of land, the view being bounded only by sea and sky, and look at the horizon when a ship (A, fig. 1) approaches, we shall at first see its topmast rising out of the water like a pole.

Fig. 1.



As it gradually comes nearer to us (as at B), more of the mast will become visible, and the sails will be seen—cut off, however, horizontally, by the line at which the water and sky unite. Upon the nearer approach of the ship (as at C and D), the hull will at length become visible. Now since this takes place on all sides around us, it will follow that when the ship is at a distance, there must be *something* interposed between the eye and it which intercepts the view of it; but as the surface of the water is generally uniform, and not subject to sudden and occasional inequalities like that of the land, we can only imagine its general form to be convex, and that its convexity is interposed between the eye and the object so as to intercept the view.

Since the same effects are observed from whatever direction the ship may approach, it will follow that the same convexity must prevail on every side.

If, on the contrary, the surface extending from the eye to the ship were a plane, the ship would be rendered invisible only by reason of its distance; whereas it is ascertained that a ship frequently is invisible at a distance at which it must be seen but for the interposition of some other object; this may be tested, and in fact is frequently tested at sea by mounting to the masthead, whence the seaman being enabled to overlook the convexity, sees vessels which are invisible from the deck, although, strictly speaking, he is nearer to those vessels on the deck than at the masthead.

When the mariner, after completing a long voyage, discovers by his observations and reckonings that he is approaching the desired coast, he ascends to the topmast and looks out for the appearance of mountains or other elevated land, and he invariably sees them from that point long before they are visible from the deck. He afterwards sees them from the deck long before the general level of the country will be observed by him. All these are natural and necessary consequences of the convexity of the surface of the ocean. The same effects would be seen in any part of a continent which is sufficiently free from mountains and other inequalities.

5. But we have a still more conclusive and convincing proof of the general form of the earth even than those which have been explained. When the moon passes directly behind the earth, so that the shadow which the earth projects behind it in the direction opposite to the sun shall fall upon the moon, we invariably find that shadow to be, not as is commonly said, circular, but such exactly as one globe would project upon the surface of another globe. Now, as this takes place always, in whatever position the earth may be, and while the earth is revolving rapidly with its diurnal motion upon its axis, it follows that the earth must either be an exact globe or so little different from a globe that its deviation from that figure is undiscoverable in its shadow.

We may, then, consider it demonstrated that the earth may be practically regarded as globular in its form. We shall hereafter see that it slightly departs from the spherical figure, but our present purpose will be best answered by regarding it as a globe.

6. The objection will doubtless occur to many minds that the inequality which exists on the surface of that portion of the globe that is covered by land, especially the loftier ridges of mountains, such as the Andes, the Alps, the Himalaya, and others, are incompatible with the idea of a globular figure. If the term globular figure were used in the strictest geometrical sense, this objection doubtlessly would have great force. But let us see the real extent of this presumed deviation from the globular form. The highest mountain on the surface of the globe does not exceed five miles above the general level of the sea. The entire diameter of the globe, as we shall presently see, is eight thousand miles. The proportion, then, which the highest summit of the loftiest mountains bears to the entire diameter of the globe will be that of five to eight thousand, or one to sixteen hundred. If we take an ordinary terrestrial globe of sixteen inches in diameter, each inch upon the globe will correspond to five hundred miles upon the earth, and the sixteen hundredth part of its diameter, or the hundredth part of an inch, will correspond to five miles. If, then, we take a narrow strip of paper, so thin that it would take one hundred leaves to make an inch in thickness, and paste such a strip on the surface of the globe, the thickness of the strip would represent upon the sixteen-inch globe the height of the loftiest mountain on the earth. We are then to consider that the highest

mountain-ranges on the earth deprive it of its globular figure only in the same degree and to the same extent as a sixteen-inch globe would be deprived of its globular figure by a strip of paper pasted upon it the hundredth part of an inch thick.

It is supposed that the greatest depth of the ocean which covers any portion of the globe does not exceed the greatest height of the mountains upon the land. If this be true, the ocean upon the earth might be represented by a film of liquid laid with a camel's hair pencil upon the surface of a sixteen-inch globe.

It is apparent, therefore, that depths and heights which appear to the common observer to be stupendous, are nothing when considered with reference to the magnitude of the earth; and that, so far as they are concerned, we may practically regard the earth as a true globe.

7. Having ascertained satisfactorily the form of the earth, our next enquiry must be as to its magnitude; and since it is a globe, all that we are required to know is the length of its diameter.

If a line were described surrounding the globe, so as to form a circle upon it, the centre of which should be at the centre of the globe, such a circle is called a *great circle* of the earth. Now if we know the length of the circumference of such a circle, we could easily calculate the length of its diameter, for the proportion of the circumference to the diameter is exactly known. But we could calculate the circumference if we knew the length of one degree upon it, since we know that the circumference consists of three hundred and sixty degrees; we should therefore only have to multiply the length of one degree by three hundred and sixty to obtain the circumference, and should thence calculate the diameter.

8. In our tract upon latitudes and longitudes, it was shown how the latitude of a place can be ascertained. Now, let us suppose two places selected which are upon the same meridian of the earth, and therefore have the same longitude, and which are not very far removed from each other. Let them, moreover, be selected so that the distance between them can be easily and accurately measured. Now let the latitude of these two places be exactly determined, and let us suppose for example that the difference between these two latitudes is found to be one degree and a half; and supposing also that on measuring the distance between them, that distance is found to be one hundred and four miles and thirty-five hundredths. We should thence infer that such must be the length of one degree and a half of the earth's surface, and that consequently the length of one degree would be two thirds of this, or sixty-nine and a half miles. Having thus found the length of

a degree, we should have to multiply it by three hundred and sixty, by which we should obtain the circumference of the earth. This would give twenty-five thousand and twenty miles, and we should then find by the usual mode of calculation the diameter of the earth, which would prove to be a little under eight thousand miles.

The fact that a degree of the earth's circumference consists in round numbers of just so many thousand feet as there are days in the year, supplies a very convenient aid to the memory.

We have made these calculations chiefly with a view of rendering the principles of the investigation intelligible. The more exact dimensions of the earth will be explained hereafter.

We conclude, then, that the earth is a globe eight thousand miles in diameter.

9. To enounce this stupendous arithmetical result is much easier than to obtain any distinct notion of the actual magnitude which it expresses. Such a globe has a circumference of twenty-five thousand miles. A locomotive engine travelling incessantly night and day, at twenty-five miles an hour, would take about forty-two days to go round it.

10. When the diameter of a globe is known, its surface and volume or cubical bulk can be easily determined. To find the surface we have only to take three hundred and fourteen hundredths of the square of the diameter, and to find the volume, five hundred and twenty-four thousandths of the cube of the diameter. In this way we find that the surface of the earth measures two hundred millions of square miles, and that its cubical bulk is about two hundred and sixty thousand millions of cubic miles.

If the materials which form such a globe were built up in the form of a vertical column, the base of which would have the magnitude of England and Wales, its height would be nearly four and a half millions of miles!

11. Such being the dimensions of the globe we inhabit, we are next to consider what is its condition as to motion. Is it, as it appears, at rest? For several thousand years in the history of the human race, it was not only so considered, but he that would have ventured to call in question its stability and quiescence would have been deemed insane. Certain expressions in the sacred Scriptures being erroneously supposed to affirm its immobility, it was deemed heretical to deny it; and Galileo, who did so, was put to the torture by the ecclesiastical authorities of the day, and compelled to admit its quiescence. This verbal admission was, however, so utterly opposed to his convictions, that, on quitting the presence of the inquisitors, he stamped on the ground, and muttered the words, "It moves for all that."

ROTATION.

12. A few hours' attentive contemplation of the firmament at night will enable any common observer to perceive, that although the stars are, relatively to each other, fixed, the hemisphere, *as a whole*, is in motion. Looking at the zenith, that is the point directly above our head, constellation after constellation will appear to pass across it, having risen in an oblique direction from the horizon at one side, and, after passing the zenith, descending on the other side to the horizon, in a direction similarly oblique. Still more careful and longer continued observation, and a comparison, so far as can be made by the eye, of the different directions successively assumed by the same object, creates a suspicion, which every additional observation strengthens, that the celestial vault has a motion of slow and uniform rotation round a certain diameter as an axis, carrying with it all the objects visible upon it, without in the least deranging their relative positions or disturbing their arrangement.

When these loose impressions of the senses are submitted to the more exact means of observation which are at the disposition of astronomers, it is found that all the appearances of the heavens, the rising and the setting of the stars, the sun and the moon, their apparent motion in ascending to, passing, and descending from, their several points of culmination, is that of a sphere revolving with an uniform motion round the diameter which is directed to the pole.

The world we inhabit therefore would, to judge from these phenomena, seem to be fixed in the centre of a hollow sphere of vast magnitude. On the concave surface of this hollow sphere thus surrounding us at an immeasurable distance all the stars appear to be placed. This sphere, carrying the whole creation upon it, appears to revolve round our world. It makes a complete revolution in twenty-four hours.* By this rotation, the diurnal appearances of the rising and setting of all the heavenly bodies are perfectly explained.

13. The ancients who, as has been stated, affirmed the reality of this motion of the celestial sphere, gave to the whole creation around the earth, the name UNIVERSE; from two words, UNUS, *one*, and VERSUM, *turning* or *rotation;* because they assumed that by an imaginary force, called the PRIMUM MOBILE, or *first impulse*, this rotatory motion had been imparted to the firmament, which ever afterwards retained it.

14. It is easy to perceive that the apparent diurnal rotation of the firmament round the earth may arise indifferently from either of two causes: 1st, from such a real rotation of the firmament

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* More exactly $23^h\ 56^m\ 4{\cdot}09^s$, but for the present the cause of this difference need not be noticed.

once in twenty-four hours; 2ndly, from the rotation of the globe of the earth in the same time round that diameter which is in the direction of the axis round which the firmament appears to revolve.

There is absolutely no other supposition possible but one or other of these. The rejection of either necessarily throws us upon the adoption of the other.

But it may be required that we should show how the rotation of the earth upon an axis passing through the poles would cause the apparent diurnal rotation of the firmament.

15. Let us assume that the earth is a globe revolving uniformly on its axis in twenty-four hours. The universe around it is relatively stationary, and the bodies which compose it being at distances which mere vision cannot appreciate, appear as if they were situate on the surface of a vast celestial sphere in the centre of which the earth revolves. This rotation of the earth gives to the sphere the appearance of revolving in the contrary direction, as the progressive motion of a boat on a river gives to the banks an appearance of retrogressive motion; and since the apparent motion of the heavens is from east to west, the real rotation of the earth which produces that appearance must be from west to east.

How this motion of rotation explains the phenomena of the rising and setting of celestial objects is easily understood. An observer placed at any point upon the surface of the earth is carried round the axis in a circle in twenty-four hours, so that every side of the celestial sphere is in succession exposed to his view. As he is carried upon the side opposite to that in which the sun is placed, he sees the starry heavens visible in the absence of the splendour of that luminary. As he is turned gradually towards the side where the sun is placed, its light begins to appear in the firmament, the dawn of morning is manifested, and the globe continuing to turn, he is brought into view of the luminary itself, and all the phenomena of dawn, morning, and sunrise are exhibited. While he is directed towards the side of the firmament in which the sun is placed, the other bodies of inferior lustre are lost in the splendour of that luminary, and all the phenomena of day are exhibited. When by the continued rotation of the globe the observer begins to be turned away from the direction of the sun, that luminary declines, and at length disappears, producing all the phenomena of evening and sunset.

Such, in general, are the effects which would attend the motion of a spectator placed upon the earth's surface, and carried round with it by its motion of rotation. He is the spectator of a gorgeous diorama exhibited on a vast scale, the earth which forms his station being the revolving stage by which he is carried round, so as to view in succession the spectacle which surrounds him.

These appearances vary with the position assumed by the observer on this revolving stage; or, in other words, upon his situation on the earth, as will presently appear.

16. That diameter upon which it is necessary to suppose the earth to revolve in order to explain the phenomena is that which passes through the terrestrial poles.

17. If the globe of the earth be imagined to be cut by a plane passing through its centre at right angles to its axis, such a plane will meet the surface in a circle, which will divide it into two hemispheres, at the summits of which the poles are situate. This circle is called the TERRESTRIAL EQUATOR.

18. That hemisphere which includes the continent of Europe is called the NORTHERN HEMISPHERE, and the pole which it includes is called the NORTHERN TERRESTRIAL POLE; the other hemisphere being the SOUTHERN HEMISPHERE, and including the SOUTHERN TERRESTRIAL POLE.

19. If the surface of the earth be imagined to be intersected by planes passing through its axis, they will meet the surface in circles which, passing through the poles, will be at right angles to the equator. These circles are called TERRESTRIAL MERIDIANS, and will be seen delineated on any ordinary terrestrial globe.

These observations will be more clearly comprehended by reference to fig. 2, in which N is the north, and S the south pole of the earth, and Æ Q the equator. The firmament surrounding the earth is represented by the circle *n æ s q*. The axis S N of the earth being supposed to be prolonged to the heavens will meet the firmament at *n* and *s*, the celestial north and south poles; and in like manner the plane of the terrestrial equator Æ Q being continued to the heavens, will meet the firmament at *æ q*, the celestial equator.

If an observer be stationed at O, his zenith will be at *z*, and his horizon at *h h′*. As the globe revolves from west to east, the heavens will be successively brought into view on the east, and will disappear continually on the west.

20. Assuming then that all the diurnal changes of appearance presented by the firmament, the risings and settings of the sun, moon, and stars, and their varying appearance in different latitudes, admit of being explained with equal precision and completeness, either by supposing the universe to revolve daily round the earth, or the earth to revolve daily on its axis, the only question which remains to be decided is, which of these two suppositions is the more probable?

The fixity and absolute repose of the globe of the earth being assumed by the ancients as a physical maxim which did not even admit of being questioned, they perceived the inevitable character of the alternative which the apparent diurnal rotation of the heavens imposed upon them, and accordingly embraced the hypothesis, which now appears so monstrous, and which is implied in the term UNIVERSE, which they have bequeathed to us.

21. But with the knowledge which has been obtained by the labours of modern astronomers respecting the enormous magnitudes of the principal bodies of the physical universe, magnitudes compared with which that of the globe of the earth dwindles to a mere point, and their distances under the expression of which the very power of number itself almost fails, and recourse is had to colossal units in order to enable it to express even the smallest of them, the hypothesis of the immobility of the earth, and the diurnal rotation of the countless orbs of magnitudes so inconceivable filling the immensity of space once every twenty-four hours round this grain of matter composing our globe, becomes so preposterous that it is rejected, not as an improbability, but as an absurdity too gross to be even for a moment seriously entertained or discussed.

22. But if any ground for hesitation in the rejection of this hypothesis existed, all doubt would be removed by the simplicity and intrinsic probability of the only other physical cause which can produce the phenomena. The rotation of the globe of the earth upon an axis passing through its poles, with an uniform motion from west to east once in twenty-four hours, is a supposition against which not a single reason can be adduced based on improbability. Such a motion explains perfectly the apparent diurnal rotation of the celestial sphere. Being uniform and free from irregularities, checks, or jolts, it would not be perceivable by any local derangement of bodies on the surface of the earth, all of which would participate in it. Observers upon the surface of our globe would be no more conscious of it, than are the voyagers shut up in the cabin of a canal boat, or transported above the clouds in the car of a balloon.

23. It has been shown that a body descending from a great height does not fall in the true vertical line, which it would if the earth were at rest, but eastward of it, which it must, if the earth have a motion of rotation from west to east.

24. An ingenious expedient, by which the diurnal rotation of the earth is rendered visible, has been conceived and reduced to experiment by M. Leon Foucault. This contrivance is based upon the principle, that the direction of the plane of vibration of a pendulum is not affected by any motion of translation which may

be given to its point of suspension. Thus, if a pendulum suspended in a room and put into vibration in a plane parallel to one of the walls, be carried round a circular table, the plane of its vibration will continually be parallel to the same wall, and will therefore vary constantly in the angle it forms with the radius of the table which is directed to it.

Now, if a pendulum, suspended anywhere so near the pole of the earth that the circle round the pole may be considered a plane, be put in vibration in a plane passing through the pole, this plane, continuing parallel to its original direction as it is carried round the pole by the earth's rotation, will make a varying angle with the line drawn to the pole from the position it occupies. After being carried through a quarter of a revolution it will make an angle of 90° with the line to the pole, and so on. In fine, the direction of the pole will appear to be carried round the plane of vibration of the pendulum.

The same effects will be produced at greater distances from the pole, but the rate of variation of the angle under the plane of vibration and the plane of the meridian will be different, owing to the effects of the curvature of the meridian.

This phenomenon, therefore, being a direct effect of the rotation of the earth, supplies a proof of the existence of that motion, attainable without reference to objects beyond the limits of the globe.

25. Another evidence of the rotation of the earth upon its axis is derived from the ascertained fact that the planets which hold places in the solar system similar to that of the earth, do revolve on axes, in times not very different from that of the earth's rotation, as has been shown in our tract upon the Planets.

It may, then, be taken as proved that the earth is not fixed and quiescent, but that it has a rotatory motion round the diameter which passes through its poles, completing a revolution in a day.

26. Having explained the proofs by which we have arrived at the knowledge of the globular form of the earth, it may occasion some surprise that we shall now have to reconsider and modify that conclusion. In this there is nevertheless nothing unusual. It is quite in harmony with all the labours of those who devote themselves to the discovery of the laws of nature.

27. It is the condition of man, and probably of all other finite intelligences, to arrive at the possession of knowledge by the slow and laborious process of a sort of system of trial and error. The first conclusions to which, in physical enquiries, observation conducts us, are never better than very rough approximations to the truth. These, being submitted to subsequent comparison with the originals, undergo a first series of corrections, the more

prominent and conspicuous departures from conformity being removed. A second approximation, but still only an approximation, is thus obtained; and another and still more severe comparison with the phenomena under investigation is made, and another order of corrections is effected, and a closer approximation obtained. Nor does this progressive approach to perfect exactitude appear to have any limit. The best results of our intellectual labours are still only close resemblances to truth, the absolute perfection of which is probably reserved for a higher intellectual state.

These observations will be illustrated by the process of investigation and discovery in every department of physical science, but in none so frequently and so forcibly as in that which now occupies us.

The first conclusions at which we have arrived respecting the form of the earth is, that it is a globe; and with respect to its motion is, that it is in uniform rotation round one of its diameters, making one complete revolution daily.

28. The first question then which presents itself is, whether this form and rotation are compatible? It is not difficult to show, by the most simple principles of physics, that they are not; that with such a form such a rotation could not be maintained, and that with such a rotation such a form could not permanently continue.

The conclusion that the earth revolves on its axis with a motion corresponding to the apparent rotation of the firmament, is one which admits of no modification, and must from its nature be either absolutely admitted or absolutely rejected. The globular form imputed to the earth, however, has been inferred from observations of a general nature, unattended by any conditions of exact measurement, and which would be equally compatible with innumerable forms, departing to a very considerable and measurable extent from that of an exact geometrical sphere or globe.

29. It is a fact familiar to every one that when a body is whirled round in a circle it has a tendency to fly from the centre. This is called CENTRIFUGAL FORCE. If a stone be whirled round in a sling, this tendency is sensibly felt.

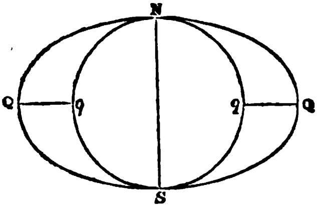
By reason of the rotation of the earth on its axis all the matter composing it, solid and fluid, being carried round the axis in circles of greater or less radius, has this tendency to fly from the axis round which it is thus whirled; and this tendency is stronger for those parts which are more distant than for those which are nearer to the common axis.

30. If the globe thus revolving were composed altogether of matter capable of yielding to the action of such forces, it would

obviously assume a form departing from that of an exact sphere. The parts near the equator would extend themselves to a greater distance from the axis, those more remote from the equator to a less distance, and so on, until, at the pole, the matter would not be at all affected by the rotation. This would be the case if the globe were formed of matter in a liquid or even in a semi-liquid or soft state, or if its materials were elastic.

The form it would take would be one resembling an orange or a turnip. Thus, if N S, fig. 3, be its axis, the equatorial diameter, *q q*, will be stretched out to the increased length, Q Q, while the parts between *q q* and the poles will be less and less extended the nearer they are to the poles, The globe would therefore be changed from the form N *q* S *q*. of a true sphere, to the form N Q S Q, of a flattened globe, called in geometry an OBLATE SPHEROID.

Fig. 3.



31. The elliptic form would depart more and more from a true circle as the motion of rotation is more rapid, so that between the time of rotation and the degree of ellipticity there is a fixed relation, such that when the time of rotation is given, the oval form, or what is the same, the proportion of the equatorial to the polar diameter, can be computed.

32. It is certain, then, that if the earth were composed of fluid, soft or elastic matter, it could not continue to retain the form of a globe, but would become a spheroid, having that degree of ellipticity which would correspond to a motion of rotation, at the rate of one revolution per day, and it is shown by calculation that this ellipticity would be such that the equatorial diameter would be greater than the polar diameter by one three-hundredth part.

33. But the earth, in its present state, is not composed of such yielding materials, and it becomes a question, what, in that case, must be the effect of the diurnal rotation on the distribution of land and water, if the earth were an exact globe.

34. The solid parts of the earth would resist by their cohesion the tendency of the rotation, to cause them to be accumulated and heaped up around the equator; but this would not be the case with the waters composing the seas and oceans. These, by reason of their freedom and mobility would yield to the centrifugal force, and would heap themselves up around the equator, flowing in that direction from the polar regions of either hemisphere, so that the necessary consequences of the earth having a form exactly

globular, and a diurnal rotation, would be that the surface would consist of two vast polar continents separated by an extensive equatorial ocean.

Such not being the distribution of land and water on the earth, it follows that its form cannot be that of an exact globe.

35. It remains, then, to find means to ascertain by direct measurement and observation, what is the actual form of the earth.

If a terrestrial meridian were an exact circle, as it would necessarily be if the earth were an exact globe, every part of it would have the same curvature. But if it were an ellipse, of which the polar diameter is the lesser axis, it would have a varying curvature, the convexity being greatest at the equator, and least at the poles. If, then, it can be ascertained by observation, that the curvature of a meridian is not uniform, but that on the contrary it increases in going towards the Line, and diminishes in going towards the Poles, we shall obtain a proof that its form is that of an oblate spheroid.

To comprehend the method of ascertaining this, it must be considered that the curvature of circles diminishes as their diameters are augmented.

If, therefore, a degree of the meridian be observed, and measured, at different latitudes, and it is found that its length is not uniformly the same as it would be if the meridian were a circle, but that it is less in approaching the equator, and greater in approaching the pole, it will follow that the convexity or curvature increases towards the equator, and diminishes towards the poles; and that consequently the meridian has the form, not of a circle, but of an ellipse, the lesser axis of which is the polar diameter.

Such observations have accordingly been made, and the lengths of a degree in various latitudes, from the Line to 66° N. and to 35° S., have been measured, and found to vary from 363000 feet on the Line to 367000 feet at lat. 66°.

From a comparison of such measurements, it has been ascertained that the equatorial diameter of the spheroid exceeds the polar by $\frac{1}{300}$th of its length.

Now this is precisely the form, precisely the degree of ellipticity, which a globe, composed of fluid or soft materials, would assume if it had a rotation on its axis once in twenty-four hours.

Thus it appears, that the form of the earth, ascertained by observation, supplies another proof of its diurnal rotation.

36. It is not enough to know the proportions of the earth. It is required to determine the actual dimensions of the spheroid. The following are the lengths of the polar and equatorial diameters,

according to the computations of the most eminent and recent authorities :—

	BESSEL.	AIRY.
	Miles.	Miles.
Polar diameter	7899·114	7899·170
Equatorial diameter	7925·604	7925·648
Absolute difference	26·471	26·478
Excess of the equatorial expressed in a fraction of its entire length . . .	$\frac{1}{299\cdot407}$	$\frac{1}{299\cdot330}$

The close coincidence of these results supplies a striking example of the precision to which such calculations have been brought.

37. The departure of the terrestrial spheroid from the form of an exact globe is so inconsiderable that, if an exact model of it turned in ivory were placed before us, we could not, either by sight or touch, distinguish it from a perfect billiard ball. A figure of a meridian actually drawn on paper could only be distinguished from a circle by the most precise measurement.

38. The magnitude of the earth being known with great precision, the determination of its mass and that of its mean density become one and the same problem, since the comparison of its mass with its magnitude will give its mean density, and the comparison of its mean density with its magnitude will give its mass.

The methods of ascertaining the mass or actual quantity of matter contained in the earth are all based upon a comparison of the gravitating force or attraction which the earth exerts upon an object with the attraction which some other body, whose mass is exactly known, exerts on the same object. It is assumed, as a postulate or axiom in physics, that two masses of matter which at equal distances exert equal attractions on the same body, must be equal. But as it is not always possible to bring the attracting and attracted bodies to equal distances, their attractions at unequal distances may be observed, and the attractions which they would exert at equal distances may be thence inferred by the general law of gravitation, by which the attraction exerted by the same body increases as the square of the distance from it is diminished.

39. To solve this celebrated problem, it is necessary to bring the whole mass of the globe into direct comparison with some object whose mass is exactly known. This was accomplished first by Dr. Maskelyne, and afterwards by Cavendish. The former compared the attraction of the earth with that of a mountain in Perthshire, called Schehallion; the latter compared it with the attraction of a large ball of metal. Both obtained nearly the

same result, showing that the earth is a mass of matter about 5⅔ heavier than an equal volume of water, or, what is the same, that the mean density of the earth is 5⅔, or, more exactly, 5·67 times the density of water.

Among the substances which have nearly the same density as the earth may be mentioned, arsenic, chromium, chloride of silver, oxides of copper and zinc, and peroxide of iron.

40. The average weight of each cubic foot of the earth being 5·67 times the weight of a cubic foot of water, is 354·375 lbs., or 0·1587 of a ton. It follows, therefore, that the total weight of the earth is more than 6000,000000 billions of tons.

COMMON THINGS.

FIRE.

1. Fire an ancient element.—2. Combustion.—3. Fuel.—4. Carbon.—5. Hydrogen.—6. Charcoal fire.—7. Its effect on the air.—8. Experimental illustration of combustion of charcoal.—9. Combustion of hydrogen.—10. How the combustion is continued.—11. Carbon burns without flame.—12. What is flame?—13. Combustion of hydrogen produces water—14. All combustibles produce carbonic acid and water.—15. Carburetted hydrogen.—16. Carbon renders flame white.—17. Olefiant gas.—18. Light carburetted hydrogen.—19. Fire-damp.—20. Will-'o-the-Wisp.—21. Experimental illustration.—22. Heavy carburetted hydrogen.—23. Pit-coal—24. Coal-fire explained.—25. Products of its combustion.—26. Its effect on the air.—27. Wood-fuel.—28. Combustibles used for illumination.—29. Their effect on the air.—30. Construction of grates and chimneys.—31. Analysis of a common coal-fire.—32. It warms and ventilates.—33. Necessity for ventilation.—34. Injurious effect of plants at night.—35. Effect of crowded and brilliantly lighted rooms.—36. Explanation of the burning of a candle.—37. And of lamps.

1. In the physical theory which prevailed among the ancients, and which maintained its ground for several thousand years, Fire was accounted as one of the elements; that is to say, as a material

essence, which with three others, air, water, and earth, constituted all natural bodies.

It was only towards the close of the last century, and within the lifetime of the elder part of the present generation, that the true character of fire was discovered.

2. It is now known that fire is neither a distinct substance nor essence, as supposed by the ancients. It is a phenomenon consisting of the sudden and abundant evolution of heat and light produced when a certain class of bodies called COMBUSTIBLES enter into chemical combination with the oxygen gas which, as has been explained in our Tract on Air, constitutes one of the constituents of the atmosphere. The term COMBUSTION in the modern nomenclature of physics has been adopted to express this phenomenon.

3. The class of combustible substances which are commonly used for the production of artificial heat is called FUEL. Such, for example, are pit coal, charcoal, and wood.

Another class of combustibles is used for the production of artificial light: such, for example, are oil, wax, and the gas extracted from certain sorts of pit coal, from oil, and from certain sorts of wood, such as the pitch pine.

4. The principal constituents of all these combustibles, whether used for the production of heat or light, are those denominated by chemists CARBON and HYDROGEN.

CARBON is the name given to charcoal when it is absolutely pure, which it never is as it is obtained by the ordinary industrial processes. It is in that state combined with various heterogeneous and incombustible substances. In the laboratories of chemists it is separated from these, and obtained in a state of perfect purity, being there distinguished from the charcoal of commerce by the name CARBON.

Carbon having never been resolved by any chemical agent into other constituents, is classed in physics as a simple and elementary body, which enters largely into the composition of a most numerous class of bodies which are found in nature, or produced in the processes of industry, the sciences, and the arts.

5. HYDROGEN has been already very fully described and explained in our Tract upon Water; we shall presently explain still more in detail its leading properties. Like carbon, it is classed as a simple and elementary substance; and also, like carbon, enters largely into the composition of a numerous class of bodies.

6. A quantity of charcoal being placed in a furnace through which a draught of air is maintained, if a part of it be heated to redness, the entire mass will soon become incandescent, and will emit a reddish light, which will be whiter as the air is passed through it more briskly, and will emit considerable heat. The charcoal will gradually decrease in quantity, and at length will

disappear altogether from the furnace, under which a small portion of ashes consisting of incombustible matter will remain. If the charcoal had been pure—that is, if it had been carbon—it would have altogether disappeared, no ash whatever remaining.

This phenomenon is an example of FIRE. The heat and light developed during the process here described are commonly called fire.

7. To comprehend what takes place in this process, we must consider that, as the air passes through the charcoal, the oxygen gas, which forms one-fifth part of it,* enters into combination with the pure carbon. A compound is thus formed consisting of carbon and oxygen. The formation of this compound is attended with so great a production of heat, that not only the compound itself, but the charcoal, from which it is evolved, is raised to a very elevated temperature.

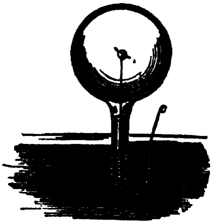
The compound thus produced is a gas called carbonic acid, which has been already briefly noticed in our Tract on Air.

The air which enters the furnace being a mixture of azote and oxygen,* that which rises from it after the combustion has been produced is a mixture of azote and carbonic acid; the azote having passed through the furnace without suffering other change than an increase of temperature, while the oxygen has been converted into highly heated carbonic acid.

Several questions, however, arise out of this explanation. How is it known that such combination really takes place between the carbon and oxygen? If it do, in what proportion do they combine? How does it appear that the azote, which forms four-fifths of the air which passes through the furnace issues unaltered?

8. To supply satisfactory answers to these questions, it is only necessary to bring the two constituents of common air separately into the presence of carbon under the conditions necessary to favour combination, and to ascertain their weights before and after the development of the phenomena.

Fig. 1.



Let a glass flask containing sixteen grains of oxygen gas be inverted over mercury, as represented in fig. 1, and let a piece of carbon weighing more than six grains, supported in a platinum spoon, be introduced into it by means of a piece of bent platinum wire; let the sun's rays, concentrated by means of a burning-glass, be then directed upon the carbon through the glass flask. The carbon will be ignited by the solar heat, and will burn in the oxygen with great splendour.

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* See Tract on Air.

When the combustion has ceased and the gas contained in the flask has cooled, it will be found that the mercury in the neck of the flask will stand at exactly the same elevation as it did before the combustion. The gas contained in the flask has therefore the same volume as before, nevertheless it is easy to show that it is by no means the same gas.

In the first place, if it be weighed, it will be found to weigh 22 instead of 16 grains; and if the unburned residue of the carbon be weighed, its weight will be found to be 6 grains less than it was before the experiment. The inference is, that 6 grains of the carbon have combined with the 16 grains of the oxygen previously contained in the flask, but that in thus combining, the carbon has not made any change in the volume of the gas.

If the gas contained in the flask be examined by the usual tests, it will immediately appear that it is no longer oxygen. No combustible will burn in it, and it will not support life by respiration. In fine, it will be found to be identical with the noxious gas called choke-damp, and to possess all the chemical characters of the gas called Carbonic Acid.

If the same flask, similarly filled with nitrogen gas or azote,[*] be submitted to a like experiment, the result will not be the same. The solar rays concentrated on the charcoal will still render it red hot, but it will not burn nor undergo any other change. On removing the focus of solar rays from it, it will become gradually cool, and when removed from the flask will have the same weight as when introduced into it. The azote which fills the flask will also be found to be unaltered.

It follows, therefore, that the FIRE produced when carbon burns in common air is nothing more than the heat and light developed in the formation of carbonic acid, by the combination of the carbon with the oxygen of the surrounding air, and that these substances combine in the proportion of 6 parts by weight of carbon to 16 of oxygen.[†]

9. It has been already shown[‡] that hydrogen combines with oxygen in the proportion of 1 part by weight of the former to 8 of the latter to form water, and that if the combination be formed in a pure or nearly pure atmosphere of the gases it is instantaneous and accompanied by an explosion. If, however, the combination take place, as it may, in common air, the phenomena will be very different.

If pure hydrogen, compressed in a bladder or other reservoir, be allowed to issue from a small aperture, a light applied to it will cause it to be inflamed. It burns tranquilly without explosion, producing a pale yellowish flame and very feeble light, but intense heat. This is the effect attending the gradual and continual combination of the hydrogen, as it escapes from the aperture, with the oxygen of the surrounding air. It may be asked why the hydrogen issuing from the aperture does not combine with the oxygen of the air without the application of a flame to it? And also, why being once inflamed by the application of such a body, its continued application becomes unnecessary?

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[*] See Tract on Air.

[†] More precisely 6·04 or 6·12 of carbon to 16 of oxygen.

[‡] See Tract on Water.

These questions are easily resolved. The hydrogen gas has an affinity or attraction for oxygen, which is not strong enough to cause their combination at common temperatures, but when the temperature of the hydrogen is greatly elevated, its attraction for the oxygen becomes so exalted, that it enters into instant and spontaneous combination with it. Now by applying the flame of a lamp or candle, or any other burning body, to the jet of hydrogen, its temperature becomes so greatly raised, and its attraction for oxygen consequently so exalted, that it enters directly into combination with the oxygen of the air which is in immediate contact with it at the moment.

10. But it is also asked, How the continuance of the combination and the consequent maintenance of the flame takes place—the candle or lamp which produced its commencement being withdrawn? This is explained by the great quantity of heat produced by the combination of the hydrogen with the oxygen. The commencement of the combination being produced by the candle or lamp, the hydrogen and oxygen themselves in the act of combining develop an intense heat, and the succeeding portion of hydrogen gas being in contact with them becomes heated and combines like the former with a fresh portion of oxygen. In the same manner, the heat developed by these being shared by the succeeding portion of gas, a further combination and development of heat takes place, and so on. Thus the combustion being once commenced, the heat necessary for its maintenance and continuance is developed in the process itself, which accordingly goes on without the necessity of being again kindled by the application of any flame.

The continuance of the combustion of carbon, whether in pure oxygen gas or in common air, is explained in the same manner.

11. The combustion of carbon differs from that of hydrogen in this, that the former takes place without the production of *flame.* The charcoal being heated to redness, and still in the solid form, enters directly into combination with the oxygen of the surrounding air, and the carbonic acid which is formed being a gas which is not

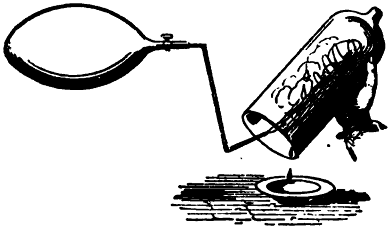
luminous nor visible, the carbon disappears. But in the case of hydrogen, the heat produced by the combustion is so intense as to render the gas itself luminous, just as intense heat will render a mass of iron red hot or white hot. When gas becomes thus luminous it is called *flame*.

12. Flame, therefore, must be understood to be nothing more than matter in the aëriform, gaseous, or vaporous state, rendered so intensely hot as to be incandescent, and to emit light, just as would a bar of iron taken from a furnace.

13. It is easy to show that, comformably with what has been already demonstrated in our Tract on Water, the product of the combustion of hydrogen is the vapour of water, which by exposure to cold can be reduced to the liquid state.

If a glass jar be held over a jet of inflamed hydrogen, as represented in fig. 2, the aqueous vapour formed by the combination of the hydrogen with the oxygen of the surrounding air, will be condensed upon the inside of the jar, and will appear first as a cloudy dew upon it, and, as the process is continued, it will increase in quantity, and, trickling down the side of the jar, may be received in drops by a dish placed beneath it.

Fig. 2.



14. As we have stated above, the principal constituents of every species of combustible, whether used for heating or lighting, are carbon and hydrogen, and the products of their combustion are therefore carbonic acid and water, the latter being evolved in the form of vapour.

15. It happens, however, rarely that the hydrogen is evolved in the pure state. It is more generally combined with a certain dose of carbon, forming a compound gas called CARBURETTED HYDROGEN. This gas burns with a much whiter and more luminous flame than that of pure hydrogen, and it is therefore much better fitted for the purpose of illumination.

16. That the flame owes its whiteness and illuminating power to the carbon with which the gas is charged, is proved by the fact,

that the more carbon the gas is charged with the whiter and brighter is the flame.

17. There are two sorts of carburetted hydrogen, one of which contains twice as much carbon as the other: the one called light carburetted or proto-carburetted hydrogen, and the other heavy carburetted or bi-carburetted hydrogen, or olefiant gas.

18. In light carburetted hydrogen 6 parts, or more exactly 6·12 parts by weight of carbon are combined with 2 of hydrogen, and heavy carburetted hydrogen contains twice that proportion of carbon.

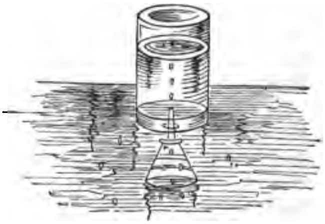
Light carburetted hydrogen is a little more than half the weight of its own bulk of common air. When pure it has no odour; and it burns with a yellowish flame much more luminous than that of pure hydrogen. Like pure hydrogen it forms a highly explosive mixture when combined in a certain proportion with common air, or, more properly, with the oxygen of common air, since the azote has no influence on the phenomenon.

19. It is this gas which, under the name of FIRE-DAMP, produces occasionally such disastrous explosions in coal mines. Being contained in large quantities in the fissures and interstices of the seams of coal, it issues from them in the workings of the mines, and being one half lighter than common air, it first collects at the top of the working. After a certain time, by a common property of all gases, it mixes with the air, and attains occasionally that proportion which renders it explosive. If a light be brought into it in this state an explosion takes place, producing those destructive consequences to the operatives who happen at the moment to be present, with the details of which the public has been so often rendered familiar.

20. This gas is also that which over marshy ground and stagnant pools produces the appearance called WILL O' THE WISP, JACK O' LANTHORN, or ignis fatuus. The gas is produced by the decomposition of vegetable and animal matter, and rising from the ground or from the water is spontaneously ignited.

21. It is easy to verify this by actually collecting the gas from any stagnant pool. For this purpose, take a common funnel used for decanting liquors, and a bottle or beer glass; immerse the latter in the water, and, when it is filled, invert it under the water and raise it above the surface, keeping the mouth under the water. Then bring the inverted funnel under its mouth, the neck entering the bottle or glass; agitate the funnel, and the gas

Fig. 3.



will rise from the water in bubbles and will collect in the upper part of the bottle or glass.

The manner of performing this experiment is shown in fig. 3.

When the gas is thus collected its inflammable nature may be ascertained by applying a light to it as it issues from the bottle.

22. Heavy carburetted hydrogen burns with a much whiter and more luminous flame. Its weight is very nearly equal to that of common air, and, therefore, nearly double that of the light carburetted hydrogen; hence it has acquired the epithet "heavy."

The products of the combustion of both sorts of carburetted hydrogen are carbonic acid and water, the former proceeding from the combination of the carbon, and the latter from that of the hydrogen with the oxygen of the air.

These points being understood it will be easy to render intelligble the effects which are developed in all ordinary cases in which FIRE or COMBUSTION takes place.

23. The species of combustible used as fuel with which we are most familiar in this country is PIT COAL.

This mineral, exclusive of some extraneous and incombustible ingredients which it contains in very small proportions, consists of carbon and carburetted hydrogen of both kinds.

The proportion of carbon varies in different sorts of coal from 80 to 90 per cent., the hydrogen varying from 3 to 6 per cent., and the remainder consisting of oxygen and azote.

In the heavy coal of Wales, called anthracite, the proportion of carbon is above 90 per cent., while that of the hydrogenous gases is only 3 or 4 per cent. In the bituminous coal of Northumberland the proportion of carbon is about 87 per cent., and that of hydrogen from 5 to 6 per cent.

24. When a fire composed of such fuel is properly kindled and supplied with a draught of air necessary to sustain the combustion, the carbon will continue to combine with its proper proportion of oxygen, producing the corresponding quantity of heated carbonic acid, and rendering the solid part of the fuel red and luminous; and the hydrogenous gases will at the same time combine with their respective proportions of oxygen, producing carbonic acid and watery vapour, and rendering the gases as they issue from the fuel luminous, or, what is the same, converting them into flame.

The flame will be faintly luminous and bluish if any part of the gases be pure hydrogen, it will be yellowish and a little more luminous if they be light carburetted hydrogen, and it will be very white and very luminous if they be heavy carburetted hydrogen.

Thus all the phenomena exhibited by a common coal-fire,—the red unflaming fuel—the faint blue flames occasionally seen,

—and, in fine, the white brilliant flame which most commonly issues from the fissures of the coal, are severally explained and accounted for.

25. It has been shown that in combustion 6 parts, by weight, of carbon combine with 16 of oxygen, or, what is the same, 1 part with 2⅔. It has also been demonstrated, that in the combustion of hydrogen, 1 part by weight of that gas combines with 8 of oxygen. Now by these simple numerical data may be easily explained the effects of a common coal-fire upon the air which feeds and sustains it.

26. It is thus found, that in burning 10 lb. of coal the oxygen contained in 1551 cubic feet of air is altogether absorbed.

To keep the atmosphere of a room in which a fire of such coal is burned fresh and pure, it would be, therefore, necessary to supply fresh air at the rate of 155 cubic feet for every pound of coal which is burned.*

27. Wood is a combustible generally used for the production of artificial heat in countries where coal is not so cheap and abundant as in England. This fuel, like coal, consists principally of carbon and hydrogen in various proportions, according to the sort of wood. All kinds of wood contain also a proportion of oxygen, as a constituent, much greater than is found in coal.

Wood, when green, contains a considerable proportion of water. In the combustion of such wood, a large proportion of the heat developed is absorbed in the evaporation of this water, and is, therefore, lost for heating purposes. Wood used as fuel should, therefore, be kept until this water, or the chief part of it, has been evaporated. For the same reason wood kept for fuel should be as little exposed to moisture or damp as possible.

28. All fatty, oily, and waxy substances are combustible, whether in the liquid or solid state. They consist of the same constituents as coal and wood, but combined somewhat differently, and in different proportions. Most of this class, burning with flame of more or less brilliancy, are used for the purposes of artificial illumination.

Whale, sperm, olive, and cocoa-nut oils, wax, spermaceti, and tallow are examples of this class of combustibles.

29. Whatever be the sort of combustible, or whatever be the purpose to which it is applied, whether for heating or lighting, it will be evident from the explanations which have been here given, that the combustion cannot be maintained with the necessary

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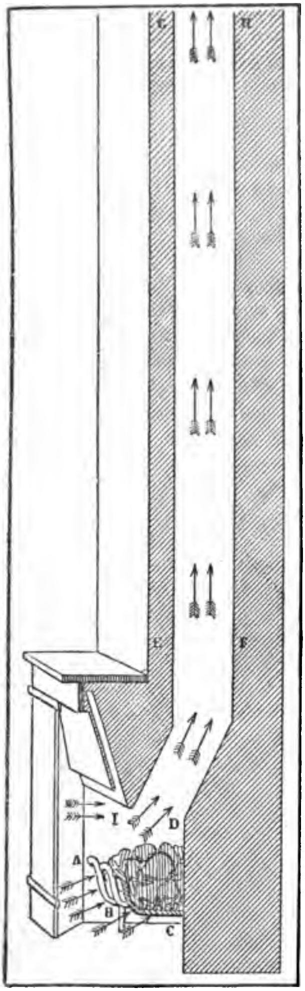
* In the preceding explanation we have omitted to take into account the effect of a small proportion of oxygen which enters into the composition of coal. This, however, is so insignificant, that it would be needless to complicate the calculation by introducing it.

activity unless expedients be provided for the supply of the quantity of oxygen which must enter into combination with it.

30. The construction of grates, stoves, and chimneys is therefore designed to attain this end by causing such a volume of common air to pass through the fuel as is necessary and sufficient to combine with it. The more air which thus passes through the fuel, the more rapid and abundant will be the combination, and the more active and vivid the combustion.

Fig. 4.



31. The current of air which passes through a common grate is produced by the draught of the chimney. The column of air included in the chimney, being raised to a higher temperature than that of the external air, is rarefied and lighter, bulk for bulk, than the external air, and is proportionately more buoyant. It has therefore a tendency to ascend like that which oil would have in water. As it ascends the air from the room must rush in to fill its place. A part of this air will pass through the bottom and front of the grate, and a part will enter at the opening of the fire-place over the grate. This will be more easily understood by fig. 4. The front of the grate is A B, and the bottom B C, having the ash-pit below it. The opening over the grate is A I, and E F G H is the flue of the chimney. The ascensional force of the column of air in the flue is measured by the difference between its weight and that of an equal volume of the external air. The air which replaces that which ascends in the flue enters the bottom B C, the front B A of the grate and the

opening A I above it, as indicated by the arrows. The former portions, passing through the burning fuel, supply to it the oxygen gas necessary to combine with it, and thus maintain the combustion. These portions after passing through the interstices of the fuel, and after the oxygen or a part of it, has combined with the fuel, issue from the top of the fuel, being then a mixture of azote, such portion of oxygen as may not have combined with the fuel, carbonic acid and aqueous vapour, the latter being the products of the combination of the oxygen with the carbon and the hydrogen of the fuel.

All these gases issuing from the burning fuel at a high temperature, and mixing with the cold air which enters the chimney through the opening A I, render the column of air in the flue so warm as to give it the buoyancy necessary to sustain the draught.

When the fire is first kindled in the grate, if the air in the chimney have the same temperature as the external air, it will have no buoyancy, and there will be no draught. In this case the chimney will generally be found to smoke. This inconvenience may be sometimes removed by opening the windows, so as to fill the room with air as cold as the external air, and therefore colder than the air in the chimney. If, however, this be found insufficient, the air in the flue may be warmed and the necessary draught produced by holding under the chimney any blazing combustible.

The draught through the grate may be greatly increased in intensity by stopping up, either partially or completely, the opening A I. By this expedient, all the air necessary to replace that which ascends in the chimney must pass through the fuel in the grate. If the magnitude of the opening be for example three times the magnitude of the front and bottom of the grate, four times as much air will thus pass through the fuel as would pass through it when the opening AF is not closed, supposing the draught in the chimney to be the same in both cases.

But, in fact, the draught in the chimney will be greatly augmented by this process: for, so long as the opening A I is not closed, the air which fills the chimney will consist of a mixture of that which passes through the burning fuel, which is raised to a high temperature, and the much larger portion which passes into the chimney through the opening A I, and which, being cold, lowers the temperature, and therefore diminishes the buoyancy of the air in the chimney. But when all the air which passes through A I, by closing that opening, is made to pass through the burning fuel, it is raised to a high temperature, which not being lowered by admixture with any air not passing through the fuel, fills the chimney with air raised to a very elevated temperature, and which therefore produces in the chimney a much stronger upward current.

Thus the effect of closing the opening A I is to stimulate the fire not only by causing to pass through it all the air which previously entered the opening A I, but also by augmenting the draught in the chimney.

32. From what has been explained above, it will be perceived that an open fireplace such as is represented in fig. 4 serves the double purpose of warming and ventilating.

All the air which enters the chimney, whether it passes through the grate or through the opening above the grate, must be replaced by an equal volume of fresh air from without, which must find its way through the interstices of doors and windows, or through other openings provided expressly for its admission. That part of the air which passes through the grate subserves the double purpose of warming and ventilation. It warms by stimulating and maintaining the combustion of the fuel, and it ventilates by leaving in the room a void into which an equal volume of fresh air must enter. That portion of air which enters the chimney through the opening above the grate has no effect direct or indirect in warming, but its effect in ventilating is just so much greater than that of the air which passes through the grate, as the magnitude of the opening above the grate is greater than the magnitude of the spaces between the bars in the front and bottom of the grate.

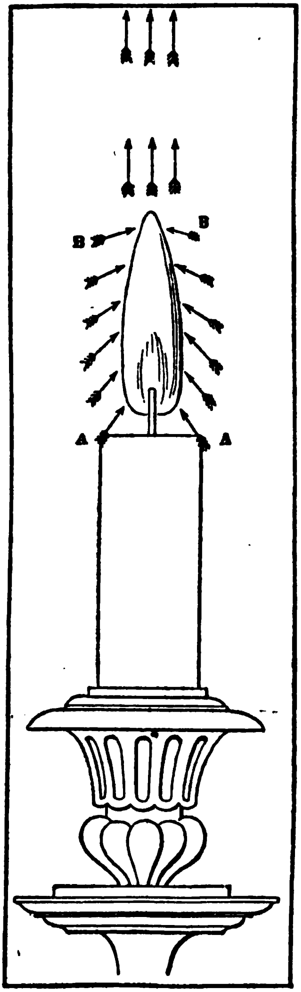
33. The necessity for ventilation is so much the greater as the room is smaller and lower, and as the causes of the pollution of its air are more numerous and active. The air of a room is deprived of its oxygen and rendered unfit for respiration by several causes. Each person who is present in the room absorbs oxygen by respiration. It is calculated that an adult of average size absorbs about a cubic foot of oxygen per hour by respiration, and consequently renders five cubic feet of air unfit for breathing. It is also computed that two wax or sperm candles absorb as much oxygen as an adult. It follows, therefore, that to keep the air of a room pure, five cubic feet for every person, and two and a half cubic feet for every candle in the room should pass per hour into the chimney, or through some other opening, and an equal volume of fresh air should be admitted.

34. Plants give out oxygen by day, but absorb it by night. Their presence in a room by day is therefore innocuous, but at night they have the effect of polluting the air, and should never be admitted except where there are ample means of ventilation.

35. A crowded room, illuminated with many candles and lamps, and, as generally happens, without a fire, soon becomes filled with air in which there is a deficient proportion of oxygen and a

corresponding volume of carbonic acid, unless means be provided, which is rarely the case, for other ventilation besides that of the chimney. Hence it arises that persons of delicate habits, especially those whose lungs are defective, in such a room, soon become sensible of general uneasiness, and are often affected with headache.

Fig. 5.



36. The manner in which the flame of lamps and candles is produced and maintained will require some explanation.

When a candle is lighted, the heat developed at the extremity of the wick melts the wax or tallow immediately below it, and thus liquefied, it is drawn up through the interstices of the wick by the force called capillary attraction. When it comes in contact with the flame, it boils, and is converted into vapour, which rises over the wick. This vapour having a very high temperature, and exercising a strong attraction for the oxygen of the surrounding air, enters into combination with it, and becoming luminous, forms the flame around and above the wick. Within the flame arises a constant current of the vapour of the combustible, and outside it currents of air carry to the surface of the flame the oxygen which produces the combustion and the light. The combustible vapour and the oxygen meeting at the surface of the flame, there enter into combination, and the vapour burns. Within the flame no combustion takes place, and no light is produced.

In fig. 5 the wick and flame are represented. Within the flame currents of combustible vapour proceed from the wick to all parts of the surface of the flame. The arrows at the sides of the flame outside its surface represent the currents of the surrounding air produced by the heat of the flame; the oxygen, being attracted by the intensely heated combustible vapour, approaches it, and, by combining with it, sustains the combustion and produces the light. The arrows above the flame indicate the current of heated air, carbonic acid and aqueous vapour, the products of the combustion which form an ascending column above the flame.

It will be apparent from what has been here stated, that the luminous part of the flame is merely superficial. The vapour within the surface of the flame not having yet come into contact with the oxygen, and therefore not having entered into combustion, cannot be luminous. The flame, therefore, so far as relates to light, is hollow, or rather it is a column of combustible vapour, the surface being the only part which burns, and therefore the only part which is luminous. As this vapour ascends from the interior of the flame, it comes successively into contact with the oxygen of the air, is burnt, and becomes luminous, the column of light gradually contracting in diameter until it is reduced to a point. The flame thus tapers to a point until all the vapour produced by the boiling matter on the wick receives its due complement of oxygen, and passes off. It speedily loses that high temperature which renders it luminous, and the flame terminates.

37. In lamps of various construction, expedients are adopted to increase the magnitude of the luminous surface of the flame, and the intensity of the combustion. This is effected by modifying the form and magnitude of the wick, by feeding it with an abundant supply of oil, and by maintaining strong currents of air at all parts of its surface to sustain the combustion.

The most common form of wick used for lamps of strong illuminating power, is that of a hollow cylinder, varying from an inch to three inches in circumference. This wick being attached at its base to a small thin ring of metal is let down into the reservoir of oil, through a space included between two concentric tubes, one of which has a less diameter than the other, the space between them being a little wider than the thickness of the wick. The wick is from two and a half to three inches long, and descends through this space between the tubes to a certain depth. This space communicates with the reservoir of oil from which the oil is forced up either by the action of a pump worked by a main spring, through the intervention of wheelwork, as in the Carcel lamp, or by the more direct action of a strong spiral spring as in the Moderator lamp, or by the pressure of oil contained in a reservoir above the level of the wick, as in the old English ring-lamp called the Sinumbral lamp, and a variety of other forms constructed on the like principle.

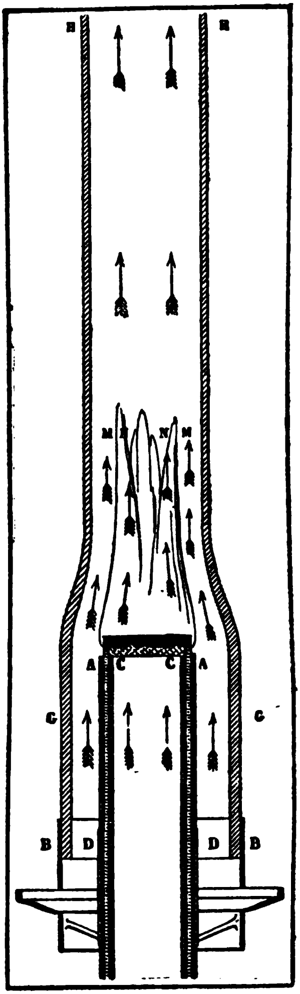
The flame issuing from such a wick is obviously a hollow cylinder, and requires to be fed with air, both at its exterior and interior surfaces. A current of air in contact with the interior surface of the flame is maintained by carrying the lesser of the two tubes between which the wick is included, down through the burner, and leaving it in communication with the external air. The exterior of the flame is exposed to the air and produces currents by its own heat, in the same manner as the currents already described, surrounding the flame of a candle.

But in the case of lamps with cylindrical burners these currents, both exterior and interior, are greatly augmented in intensity by the addition of a cylindrical glass-chimney of considerable height, the inner diameter of which a little exceeds the exterior diameter of the wick. This chimney being open at its base, and confining a column of air of its own height, acts upon the combustion of the lamp exactly as a common chimney acts on the combustion of fuel in a grate. The air which enters at the bottom, between this chimney and the burner, rises in a cylindrical current around the exterior of the wick, and passing in contact with the exterior surface of the combustible vapour proceeding from the oil, ignites it at that surface. The column of air which ascends at the same time through the inner tube passing in contact with the inner surface of the vapour ignites it in like manner. In this manner, a thin cylinder of oily vapour rising from the wick is kept in a state of vivid and constant combustion, both on its interior and exterior surfaces.

The force of these currents, exterior and interior, depends on the buoyancy of the column of air included in the chimney, and which also extends to a considerable height above it. The air after passing the flame of the lamp, being at a very high temperature, the glass-chimney itself becomes intensely hot. The column of air within the chimney being thus heated, it ascends to a considerable height above the chimney before it is cooled down to the temperature of the surrounding air. The force of the draught which maintains the currents around the flame is then determined by the difference between the weight of the column of air, extending from the base of the chimney to that height above it, at which the temperature of the ascending column becomes equal to that of the external air, and the weight of an equal volume of the external air.

This explanation of the combustion of the oil in a cylindrical burner will be more clearly comprehended by reference to fig. 6, where C C represents the interior, and A A the exterior tube, between which the wick is included. The oil is forced up to the wick in the space between these tubes; G H G H is the chimney, open at the base B B. The air ascends as indicated by the arrows between G H and D A, and passes in contact with the external surface of the flame, and it rises through the internal tube C C, passing in contact with the internal surface of the flame, as indicated by the arrows. The cylindrical flame, ascending from the wick, is represented at A M C N, and the course of the ascending column in the chimney is represented by arrows.

Fig. 6.



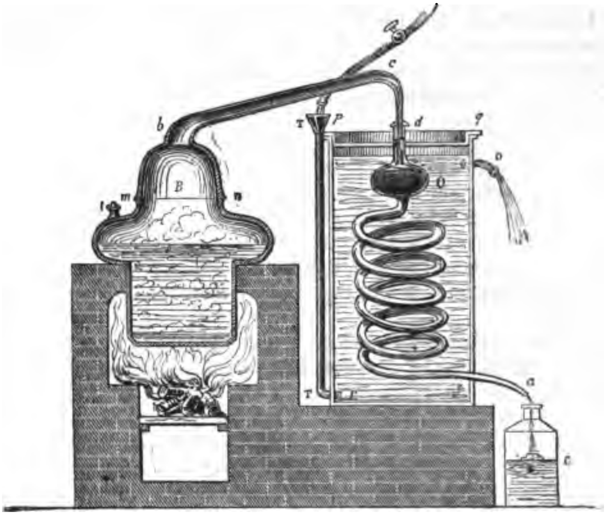


Fig. 1—DISTILLING APPARATUS.

COMMON THINGS.

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WATER.

1. Water may be solid, liquid, or vapour.—2. Colourless and tasteless.—3. Its weight.—4. Expands by heat.—5. Point of greatest density.—6. Freezing-point.—7. Boiling.—8. Evaporation.—9. Heat absorbed in evaporation.—10. Superficial evaporation.—11. Saturation of air by vapour.—12. Process of drying.—13. Case of roads and paths.—14. Drying linen.—15. Wind promotes drying.—16. Water never naturally pure.—17. Contains fixed air.—18. And other substances in solution—Hard water.—19. Soft water.—20. Mineral springs.—21. Filtration.—22. Filtering-paper.—23. Artificial filters.—24. Water not absolutely colourless.—25. How to obtain water absolutely pure.—26. Rain water nearly so.—27. River water.—Thames water.—28. Water not an element—Its composition.—29. Methods of purifying it.—30. Distillation of water.—31. Conversion of vapour into water.—32. Weight of vapour.—33. Condensation.—34. Distilling apparatus.—35. Composition and decomposition.—36. Oxygen and hydrogen.—37. Hydrogen.—38. Fitted for balloons.—39. Inflammable.—40. Water produced by combining oxygen and hydrogen.—41. Apparatus for this experiment.—42. Composition of water.—43. Analysis of water.—44. By voltaic current.—45. By other methods.—46. By potassium and sodium.—47. By iron.

COMMON THINGS.—WATER.

1. Next to air water is the most common of natural substances. It is less universally present, and although the uses to which it subserves are not less numerous and important, the want of it on the part of the animal and vegetable creation cannot be regarded as so incessant.

Water, according to certain varying physical conditions, may exist either in the solid, liquid, or vaporous state. It is perhaps in the last state that it is most universally diffused over the surface of the globe; but not being so obvious to the senses as it is when in the former two states, it is not recognised except by those who are familiar with the scientific tests of its presence.

It is therefore in the liquid form that we are most familiar with it.

2. At ordinary temperatures, and exposed to common atmospheric conditions, pure water is a colourless and tasteless liquid, having great transparency.

3. Its weight in relation to its bulk is very easily remembered, for it has been found that a cubic foot weighs almost exactly a thousand ounces, the temperature being 60°, the ordinary temperature of the atmosphere in these climates.

It may also be easily remembered that an imperial gallon of pure water, at this temperature, weighs 10 lb., and consequently that an imperial pint or the eighth part of a gallon weighs 1¼ lb.

4. All liquids expand or swell when heated, and contract when cooled. This is a general fact with which every one is familiar. Water is not an exception to this. A gallon of boiling water will be less than a gallon when it becomes cold, and a gallon of cold water will be more than a gallon when it is heated.

Water is therefore rendered more dense, that is to say, heavier in a given bulk, by cooling it, and less dense, that is lighter in a given bulk, by heating it.

5. There is, however, at a certain point in the thermal scale, a very striking exception to this general law in the case of water. If it be gradually cooled, its dimensions will continually contract, and it will become denser and denser until its temperature is reduced to $38^{\circ}\frac{8}{10}$ of Fahrenheit's thermometer. But when it is cooled below that point, instead of contracting, it is found to expand; instead of becoming denser and heavier, it becomes less dense and lighter.

Water, therefore, bulk for bulk, is heavier and denser at the temperature of $38^{\circ}\frac{8}{10}$ than at any other temperature, whether higher or lower.

This is therefore called the "temperature of greatest density."

6. When the temperature is reduced to 32° water becomes solid. This change from the liquid to the solid is called congelation

or freezing, and the temperature 32° at which it takes place, is called the freezing point of water.

7. If water be exposed to any source of heat, such as a fire or a lamp, it will, as may be naturally imagined, become continually hotter and hotter, but this increase of heat will not be unlimited. It will, on the contrary, after a certain continuance of the action of the fire or lamp upon it, attain a degree of heat or temperature which it will never exceed, however intense or long continued the action of the fire may be. In the ordinary state of the atmosphere, this temperature is that marked 212° on the thermometer. If a thermometer be immersed in the water, it will stand constantly at this temperature, although the action of the fire upon the water still continues.

When the water attains this stationary point of temperature it will be observed to be affected by a violent agitation throughout every part of it. Bubbles of vapour are formed at the parts of the vessel which are next the fire, and these rising with a certain violence, escape continually from the surface and produce the peculiar agitation of the liquid which has been just mentioned.

This state of water is called EBULLITION or BOILING, and the stationary temperature of 212°, at which it takes place, is called the BOILING POINT of the thermal scale.

8. Until the water exposed to the action of fire has attained the boiling-point, the heat imparted to it is employed in raising its temperature, or, in familiar language, in rendering it hotter. But after it has attained the limit of its temperature, and ceases to be rendered hotter, the fire still continues to impart the same heat to it, and it may be asked, What becomes of this heat? How is it absorbed, employed or disposed of? since it is certain that the water does not receive it.

This is easily explained. The water which the vessel contains does not become hotter, and therefore can receive none of the heat imparted by the fire, but it is rapidly converted into vapour, and this vapour, escaping continually from the surface of the water, rises into the air. The quantity of water in the vessel is continually diminished by the quantity thus escaping in the form of vapour, and if the process be continued, the water will altogether disappear from the vessel, being all converted into vapour.

The heat, then, imparted by the fire, in this case, and which fails to augment the temperature of the water in the vessel, is altogether absorbed by the vapour into which the water is converted. This vapour, it is true, is not hotter than the water in which it is formed, its temperature, like that of the water, being 212°; but it is proved by experiments, made in the laboratories of chemists and philosophers, that much more heat is required to impart to vapour the temperature of 212° than to impart the same temperature to water, and it is in raising the vapour formed from the water to the temperature of the water itself that the entire quantity of heat received from the fire is absorbed.

9. Thus it is found that a given weight of water at 212° when it passes into vapour, absorbs as much heat as would be sufficient to raise five and a half times the same quantity of water from the freezing to the boiling-point.

10. It is not alone when raised to the boiling-point that water is converted into vapour. It is vapourisable more or less at all temperatures, and it has been ascertained that a vapour is produced even from ice. But the evaporation which takes place from water below the boiling-point, is produced in a different manner, and under different conditions. At the boiling-point, water is converted into vapour at all points and at every depth, and most abundantly at those parts where it is in contact with the surface of the vessel upon which the fire acts. But at other temperatures the evaporation is altogether superficial. The vapour is evolved from the surface of the water above, and rises into and mingles with the stratum of air which rests on the surface of the water. This evaporation is also infinitely less rapid and copious than that which is produced by raising the whole mass of water to the boiling-point, and maintaining it at that point.

11. The stratum of air which rests upon the surface of water may be regarded as a medium which has a certain limited power of absorbing the vapour of the water, exactly as a sponge receives liquid water into its numerous pores. The air, like the sponge, has a limited capacity for vapour, and it may become so charged with vapour as to be incapable of absorbing more. The air in this case is said to be *saturated* with vapour.

Evaporation from the surface of water, therefore, takes place more or less freely and copiously as the air is more or less below the point of saturation; and when the air has already attained the point of saturation all evaporation ceases.

12. The process of drying moist or wet objects is an example of the effects of evaporation. The moisture upon the surface, or in the texture or pores of the object is evaporated by exposure to the air, and the object becomes free from moisture, or dry. This evaporation takes place so much the more rapidly as the air is below the point of saturation, and so much the more slowly as it is nearer to that point.

13. Every one is familiar with the fact, that wet roads and footpaths will on some days be dried in a few hours, while on others they will continue wet without any marks of drying. These are mere consequences of the state of the air in relation to

the vapour with which it is charged. In the former case it is under-charged, and therefore readily receives the evaporation from the roads and footways, which accordingly become dry; in the latter it is surcharged, and is at or near its state of saturation; it can receive no more vapour; no evaporation is possible, and the roads remain wet although no rain fall.

14. Washerwomen who spread linen in the air to be dried, well know that the facility of drying it varies on different days. Some days have no drying power, the air being saturated with vapour. Others dry the linen easily and quickly. Then the air is little charged with vapour, and is far below the point of saturation. Between these there are many degrees in which the facility of drying varies.

15. Wind stimulates evaporation, and therefore expedites drying. This is easily explained. So fast as the stratum of air over water becomes charged with vapour and raised towards its point of saturation, it is swept away, and a fresh portion of dry air is brought into contact with the wet surface. This in its turn is swept away, giving place to another dry portion of air, and so on. In this way, all moist objects exposed to wind or currents of air are speedily dried.

Wet objects are quickly dried when exposed to artificial heat, the moisture they contain being rapidly evaporated.

16. Water when absolutely pure is without taste, and insipid. But in its natural state water never is pure. Spring water raised from inferior strata of the ground has always various earthy and saline matters dissolved in it. In fact, every constituent of the strata from which it has been raised, or through which it may have passed, which is soluble in water, is necessarily dissolved in it in greater or less quantity. River water contains more or less of all the soluble constituents which it encounters either at its sources or on the beds and banks of the channels through which it has passed, besides the soluble parts of various dead animal and vegetable matter which it inevitably receives in its course.

17. All water in its natural state contains more or less fixed air mixed with it. This is most commonly carbonic acid. This gas, which is the same as that which effervesces in soda water, lemonade, champagne, and bottled malt liquors, gives to the flavour of water a certain agreeable pungency.

18. Water acquires very various flavours and other qualities, according to the nature of the substances which it holds in solution. Spring water, in general, even when it is most pure, holds lime and silicious earths in solution. It is from these that it acquires the quality popularly called hardness. It will not easily mix with soap, and it is not suited to culinary purposes.

19. Water which is free from this quality, and which holds but

little earthy matter in solution, is called, on the contrary, soft water. Rain water and river water is in general soft, although the latter is never free from some portion of earthy combination.

20. Mineral springs are examples of water holding peculiar mineral salts in solution, in quantities so considerable and of qualities so peculiar as to render it altogether unfit for common use. It acquires, however, from these, peculiar medicinal virtues.

21. Water generally holds suspended in it various impurities which are not dissolved in it. Muddy water is an extreme example of this. But without being actually muddy, water often has many impurities, suspended without being dissolved in it. All such impurities are removed by FILTRATION.

22. In chemical researches, where the quantities of liquid operated on are usually small, a species of paper, called filtering paper, is used. This is white unsized paper, which is formed into a conical bag, and placed in a glass funnel of corresponding shape. The liquid to be filtered is made to pass slowly through the pores of the paper, by which it is strained of the foreign matter suspended in it.

23. The filters used in the arts and in domestic economy for the purification of water have been very various. An open grained stone from Teneriffe was formerly much used for this purpose, as also porous unglazed earthenware. These have been more recently, however, completely superseded by a variety of artificial filtering apparatus, which for the most part consist of strata of gravel, sand, and charcoal powder, through which the foul water is pressed by its own weight, and by which it is very effectually strained of its solid impurities.

24. It has been stated that water is transparent and colourless; and, so far as respects any moderate quantity of the liquid which is submitted to observation, this is true. But, strictly speaking, water is neither absolutely transparent nor absolutely destitute of colour. If we look into the sea, where the water has any considerable depth, we find that its colour is a peculiar tint of blue; but if, however, we take up a glass of the water, which thus appears blue, we shall find it limpid and colourless. The reason of this is, that the quantity of water contained in the glass reflects to the eye too small a quantity of the colour to be perceivable; while the great mass of water viewed when we look into the deep sea, throws up the colour in such abundance as to produce a strong and decided perception of it.

The same is true of all transparent coloured liquids. Sherry in a decanter has a deep golden colour. Seen through the thin stem of a tapering champagne glass it appears paler and paler, until towards the point of the cone it loses all colour.

It is probable that the colour of water arises partly from the substances which it holds in solution. The fresh water of a lake has a colour different from that of the salt water of the sea. How far the colour of water may arise from the various substances which it holds in solution is difficult to decide, inasmuch as we cannot obtain a sufficient quantity of water absolutely pure to bo enabled to ascertain its proper colour.

25. It appears from what has been explained that filtration only disengages from water the solid impurities which may be mechanically mixed with or suspended in it; and if all water in the natural state holds in solution more or less foreign matter, it may be asked how water absolutely pure can be obtained?

It must be observed that, for all ordinary purposes, water chemically pure would be less suitable than such water as is commonly obtained. For alimentary purposes, absolutely pure water would be neither agreeable nor sanitary. For culinary and domestic purposes such purity is not needed.

26. Of all water found in the natural state, rain water is the purest. But this, as commonly obtained, having first fallen on the roofs of buildings, and then passed through pipes and conduits to the reservoirs in which it is collected, takes up and dissolves more or less of the impurities formed upon the surfaces over which it passes. To obtain rain water in perfect purity, it must therefore be received directly as it falls in clean vessels. But even then it is found to be impregnated more or less with air, and especially with carbonic acid, which it absorbs from the atmosphere. Minute portions of ammoniacal salts are also found in it, and if it fall near the sea, it has generally a small portion of common salt in solution. Rain which falls during thunder storms has often traces of nitric acid, formed probably by the effect of the atmospheric electricity.

27. Next to rain water, river water is the purest. The Thames water, where it is not polluted by the drainage of the metropolis, is found to contain no more than two grains of foreign matter in solution in a pint. The matter which it thus holds in solution is principally carbonate and sulphate of lime, common salt, chloride of magnesium, and animal matter. A gallon of Thames water in its most impure state, when properly filtered, does not contain more than twenty-four grains of earthy or saline matter, and in its purest state not less than sixteen grains.

When water is contaminated by animal and vegetable matter, if kept for some time, it undergoes a spontaneous purification, losing its offensive odour and colour, and depositing more or less sediment. Water for the supply of ships is well known to undergo this process of purification by fermentation, and the larger the quantity of destructible matter suspended in it, the more complete and rapid is its purification. A preference is given to Thames water for marine stores on this account, the more pure river water fermenting less rapidly, and remaining more or less foul and putrid for a much longer time.

For the supply of London, however, where this spontaneous purification is not to be waited for, it is obvious that the water should be taken from that part of the river above Richmond which is beyond the influence of the tides, and where it is not liable to be polluted by the contents of the sewers, the offal of manufactories, and the mud stirred up by steamers.

28. Water was supposed by the ancients to be one of the elements or simple substances of which all others are composed. It was ascertained, however, towards the close of the last century, that it is a compound of two substances as different in their form and properties from water itself as can well be imagined. Water is a heavy liquid. Its constituents are light gases, one of them being the lightest material substance ever yet discovered. Water is an antagonist of fire. One of its constituents is the most highly combustible substance in nature, and the other is a gas whose presence is necessary to fire, and hence called a supporter of combustion. In order to demonstrate the composition of water, it is necessary, in the first instance, to obtain that liquid absolutely pure, and it has been already stated that it is never so found naturally.

29. All fixed air with which water is charged may be dismissed from it by boiling; but to separate it from such matters as it may hold in solution, it must be submitted to the process of DISTILLATION.

30. The principle of distillation is easily explained.

If water which holds in solution any earthy or saline substance be raised to its boiling point, it will be converted into vapour, but the substance it holds in solution will not be so converted. As the water is gradually evaporated, the substance held in solution remaining undiminished, the solution first is rendered stronger and more concentrated, inasmuch as the same quantity of saline matter is dissolved in a less quantity of water. As the process goes on, the entire quantity of water will at length be evaporated, and the earthy or saline matters which it held in solution will remain in the vessel in which the evaporation takes place. This is an experiment which may be tried by any person. Let a tablespoonful of water, in which salt has been dissolved, be held for some minutes over the flame of a spirit lamp. The liquid will boil, and will soon be entirely converted into vapour, the salt alone remaining in the spoon.

31. But when it is the object, as in distillation, to obtain, not the matters held in solution by the water, but the pure water itself separated from these matters, it is necessary to prevent the vapour

from escaping, and to reconvert it into water. Now, as water is converted into vapour by heat, so, on the other hand, vapour is reconverted into water by cold. If, therefore, an apparatus be so constructed that as the vapour rises from the boiling water it shall be received into a close vessel where it is exposed to the contact of a cold surface, it will be restored to the liquid form, and being collected in that state, it will be so much pure water; pure, at least, so far as it has been separated from the substances which it held in solution before it underwent the process of evaporation.

32. The vapour of water is many hundred times lighter, bulk for bulk, than water itself. It has resulted from accurately conducted experiments, that a gallon of water evaporated at the temperature of 212° will produce nearly 1800 gallons of vapour. It follows, therefore, that when vapour is reconverted into water by exposure to cold, a very great volume of it will produce a very small volume of water. Thus, to produce a gallon of pure water, we must have nearly 1800 gallons of vapour.

33. It is for this reason that the conversion of vapour into water has been called CONDENSATION, and the apparatus in which such change is produced has been called a CONDENSER. The vapour is condensed, because it is reduced to a bulk 1800 times less, and is, therefore, rendered 1800 times denser and heavier.

The process by which water is first converted into vapour and then restored to the state of water is called distillation, from a Latin word DISTILLATIO, which signifies "falling in drops." The conversion of the vapour into liquid in the condenser usually proceeds so slowly that the liquid falls from the spout of the condenser, not in a continuous stream, but in a succession of drops.

34. In the industrial arts, and in chemical laboratories, where water absolutely pure is needed in considerable quantities, its distillation is conducted in an apparatus which is represented in fig. 1.

This distilling apparatus, or alembic, consists of a copper boiler, A, fixed in a brick furnace, having a dome-formed cover, B, adapted to it, from which a bent tube, *b c d*, proceeds, and is connected with a spiral tube called a *worm*. This worm is inclosed in a large cylindrical cistern, *p q j r*, constructed in metal, and which is kept constantly filled with cold water. The lowest part of the worm passes out of this cistern near its bottom, and terminates at *a*, over the mouth of a jar, *c*, intended to receive the distilled water. An opening, *t*, having a steam-tight stopper, is provided in the boiler, through which the water to be distilled is introduced into it.

The vapour issuing from the boiler through the tube, *b c d*, passes into the worm, being first received by the vessel, O, where the condensation begins.

Passing next through the coils of the worm, it is exposed to the contact of its cold surface, and is entirely condensed and reduced to the liquid state before it arrives at the lower extremity, *a*, from which it trickles in drops into the jar, *c*.

The heat disengaged from the vapour in the process of condensation being constantly imparted to the water in the cistern, *p q j r*, that water would be gradually warmed, and if it were not discharged and replaced by cold water, it would no longer keep the worm cold enough to condense the vapour. A supply of cold water is therefore introduced through a pipe, T T, while the heated water flows away through the pipe of discharge, *o*.

Heated water being lighter, bulk for bulk, than cold water, will float upon the latter without mixing with it, unless the liquid be agitated. The cold water, therefore, being introduced at the lowest part, T, of the cistern, will form the inferior strata, while the heated water will collect at the superior strata, and being pressed upwards by the cold water will flow out at *o*. The supply pipe, *p*, which feeds the pipe, T T, and the discharge pipe, *o*, may be, and generally are, so regulated that the water discharged from *o* is very little below the temperature of the vapour coming from the boiler, while the water of the lowest strata is as cold as the external atmosphere. The vapour, therefore, which enters at *d*, is at first only partially condensed, the condensation being rapidly increased, as winding through the worm it passes in contact with a surface colder and colder, until, at length, arriving at the lowest coil, it is wholly condensed.

The heated water which flows from the discharge pipe, *o*, may be used to feed the boiler, B; and being already at a high temperature, an economy of fuel is thus effected.

When extreme purity is required in the distilled water, it is evaporated at a temperature lower than 212°, because at that temperature a certain small portion of the foreign matters which it holds in solution sometimes go over in the vaporous state through the worm, and are ultimately deposited in the jar, *c*. The lower the temperature at which the water in the boiler is evaporated, the less of this impurity will pass through the worm.

By these expedients, with proper precautions, water absolutely pure, and entirely free from all foreign matter, may be obtained.

35. It remains now to show how the compound nature of this liquid can be demonstrated, and the characters and proportions of its constituents ascertained.

This may be accomplished by either of two methods; by COMPOSITION OF DECOMPOSITION, or, if the Greek derivatives be preferred, by SYNTHESIS OR ANALYSIS.

The method by synthesis presumes the previous knowledge of the constituents, and consists in showing, that by combining these constituents water may be produced.

The method by analysis presumes the previous discovery of some physical agent capable of overpowering the mutual attraction by which the constituents of water are held together, and tearing them asunder, and exhibiting them separated one from the other, so that their characters and properties may be ascertained.

Since the question itself is of the very highest interest and importance, and since both the methods of synthesis and analysis are in themselves most instructive and easily intelligible, we shall here explain them.

36. There are two airs or gases known to chemists, and denominated oxygen and hydrogen.

A general idea of oxygen and its leading properties has been already given in our Tract on Air.

Hydrogen, like gases in general, is an invisible colourless air, which when perfectly pure is without taste or odour. But as commonly produced it is mixed with very minute proportions of impurities, which impart to it a peculiarly disagreeable odour, with which every one is rendered familiar by the occasional leakage of the pipes used for gas-lighting.

37. This gas is the lightest of all material substances, being bulk for bulk more than fourteen times as light as common air.

38. For this reason it is eminently fitted for the inflation of air-balloons. Two thousand cubic feet of this gas will weigh only about 11 lbs., while the same volume of common air will weigh about 160 lbs. A balloon, therefore, which would contain 2000 cubic feet of hydrogen would have a buoyancy or tendency to ascend, amounting to 149 lbs., and if the silk bag, cordage, and car, with its load, have less than this weight, it will have an ascensional force equal to the excess.

39. Hydrogen is one of the most inflammable bodies in nature. It burns with a very pale bluish flame, giving very little light, but intense heat.

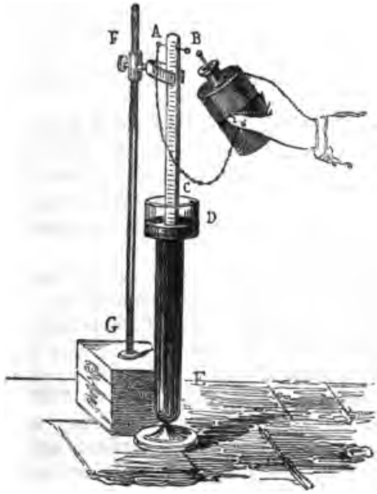
40. If a mixture of oxygen and hydrogen gases be introduced into a strong glass vessel, and be shut into it by closing the stop-cock in the pipe by which the gases are introduced, an electric spark transmitted through the mixture will inflame the hydrogen gas, and an explosion will take place, after which the glass vessel will appear to be filled with vapour, and will acquire an increased temperature. When, after a short interval, it cools, the inside surface of the glass will appear to be bedewed. Water will trickle down the sides. A certain quantity of gas will remain in the vessel. If this gas be examined by the usual tests it will be found that it is no longer a mixture of oxygen and hydrogen, but is one

or the other gas in its separate and pure state. Whether it be pure and unmixed oxygen, or pure and unmixed hydrogen, will depend on the proportions in which the gases were originally mixed in the vessel before the explosion.

41. There are many forms of apparatus by means of which this important experiment may be performed. One of them is represented in fig. 2.

A cylindrical vessel, D E, wider at the top than below, is filled with mercury. A graduated tube, B C, of thick and strong glass, about an inch in diameter, closed at one end, B, and open at the other, C, being filled with mercury and stopped by the hand at the open end, is inserted and plunged in the mercury in the cistern, D E. The mercury will not fall out of B C, because the atmospheric pressure acting on the external surface of the mercury in D E will support it. The gases, oxygen and hydrogen, may now be introduced into B C, by discharging them in the mercury under the open mouth of the tube, B C. They will rise in bubbles through the mercury, and will displace a portion of that liquid in the top of the tube, B C. In this manner any desired proportions of the gases may be introduced into the tube, B C, limited only by the capacity of the tube.

Fig. 2.



Near the top of the tube, B C, two small holes on opposite sides are bored, through which two pieces of platinum wire are inserted, terminating inside and outside in knobs. The inside knobs are close to each other, without being actually in contact. When the knob of a charged electric jar is presented to B, while A is connected by a metallic chain with the outside coating of the jar, the electric discharge will pass between the two inner knobs, and will inflame the hydrogen contained in the tube, B C.

It is in experimental researches of this kind more convenient to express the quantities of the gases by their measures as indicated by the graduation of the tube, B C. It will render this explanation, however, more easily intelligible to express them by their weights.

Let us then suppose, in the first instance, that 1 grain of hydrogen and 12 grains of oxygen are contained in B C. When the electric discharge is transmitted, the hydrogen inflamed, and the tube, B C, cooled, water and gas, as already stated, will be found in it. If the water be exactly weighed, it will be found to amount to 9 grains, and the gas will amount to 4 grains. If these 4 grains of gas be examined they will be found to be pure oxygen. Thus this residual gas will not be inflammable, but if a lighted taper be plunged in it, the flame will become larger and brighter. In a word, it will have all the properties of pure oxygen, explained in our Tract on Air.

It appears, then, that of the mixture of 1 grain of hydrogen and 12 grains of oxygen, which were in B C before the explosion, the entire grain of hydrogen has entered into combination with 8 of the 12 grains of oxygen, and has produced 9 grains of water, the other 4 grains of oxygen remaining unchanged in B C.

It follows, therefore, that the gases hydrogen and oxygen, being combined in the proportion of 1 grain of the former to 8 of the latter, produce water.

If 2 grains of hydrogen and 8 of oxygen had been introduced into B C, the explosion would still produce 9 grains of water, but in this case the residual gas would be 1 grain of hydrogen. Thus 1 of the two grains of hydrogen, combining with the 8 grains of oxygen, would produce 9 grains of water, while the other grain of hydrogen would remain in its pure and separate state.

If 1 grain of hydrogen and 8 of oxygen had been introduced into B C, the explosion would have converted the whole of the gases into 9 grains of water, and no residual gas whatever would be found in B C.

From all this we must infer that water is a compound liquid, whose constituents are the two gases, oxygen and hydrogen, combined in the proportion of 8 parts by weight of the former to 1 of the latter.

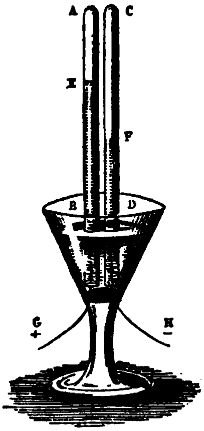
42. It follows, therefore, that one-ninth part of water, the natural antagonist of fire, is the most inflammable of bodies, and the other eight-ninths is a body without whose presence fire cannot exist.

Having thus explained the manner in which water is produced by the combination of its two constituents in due proportion, it now remains to show how the liquid itself may be resolved into its constituent gases.

43. There are several methods of accomplishing this, but the most direct and simple is by submitting water to the action of a voltaic current of sufficient force. It has been proved that the poles of a voltaic battery have specific attractions for different

bodies; the positive pole for some, and the negative for others. Now it happens that of all natural bodies that for which the positive pole has the strongest attraction is oxygen, and one of those for which the negative pole has a strong relative attraction is hydrogen. If, therefore, under certain conditions the two poles be brought to act on water, it may be expected that its decomposition will ensue, the oxygen being disengaged at the positive, and the hydrogen at the negative pole, and this in fact does take place.

Fig. 3.



44. Various forms of apparatus have been contrived for the exhibition of this experiment. The most simple and instructive is represented in fig. 3.

Two small holes are pierced near the bottom of a wine-glass, through which the ends of two wires, G and H, being inserted, so as to rise to the height of an inch or two near each other in the glass, they are cemented in the holes by mastic. These wires are put in connection, one with the positive or + pole, and the other with the negative or — pole of a voltaic battery. Water, slightly acidulated to give it more conducting power for electricity, is then poured into the glass, and two graduated glass tubes, A B and C D, each about half an inch in their interior diameter, being first filled with acidulated water, and being stopped at the open ends by the hand, are inverted and immersed in the glass, one over each of the wires. The water will then be supported in the tubes by the atmospheric pressure.

The electric current will now immediately begin to flow from the extremity of one wire through the water to the extremity of the other, and by its attraction the water will be decomposed, the oxygen constituent being attracted to the extremity of the positive, and the hydrogen to that of the negative wire. These gases will be therefore disengaged at the points of the wires as if they issued from them, as they would from small apertures in vessels containing them. They will be seen rising rapidly in small bubbles in each of the tubes, in the upper parts of which they will collect, displacing the water and pressing it downwards. After a short time, the tube containing the negative wire will be filled with gas, the water being totally expelled from it from the top to the level of the water in the glass, and at the same time the tube over the positive wire will be half filled.

Thus it appears, the tubes being of equal capacity, that the volumes of the two gases produced are in the proportion of 2 to 1, the volume of hydrogen being twice that of oxygen.

It will be further observed, that continually throughout the process of the experiment, the same proportion is maintained between the volumes of the gases evolved. At every stage of the process, the volume of hydrogen, C F, evolved, is found to be exactly double that of the oxygen, A E.

But a comparison of the weights of these two gases, bulk for bulk, proves that oxygen is sixteen times heavier than hydrogen. It follows from this that the weight of the double volume of hydrogen evolved in the experiment here described, will be exactly one-eighth of the single volume of oxygen simultaneously evolved.

Thus it appears that the water is decomposed by the voltaic current, and that its constituents are the gases oxygen and hydrogen, in the proportion of 8 parts by weight of oxygen to 1 of hydrogen.

46. Certain metals which are obtained in the laboratories of chemists, though unknown in the arts, such as potassium and sodium, have so strong an attraction for oxygen that they cannot be exposed in the atmosphere without spontaneously combining with that constituent of it. If a piece of one of these metals be plunged in water, it will exert an attraction on the oxygen of the water so powerful as to separate it from the hydrogen. The oxygen will, in virtue of this attraction, desert the hydrogen, and, combining with the potassium or the sodium, will form potash or soda, while the hydrogen, disengaged in the form of gas, may be collected in a glass receiver in the usual way. If the potash or soda thus produced be weighed, it will be found to be heavier than the potassium or sodium, by the weight of the oxygen which has entered into combination with it, and this excess of weight will be exactly eight times the weight of the hydrogen which is disengaged; from which it follows as before that water consists of 8 parts by weight of oxygen and 1 of hydrogen.

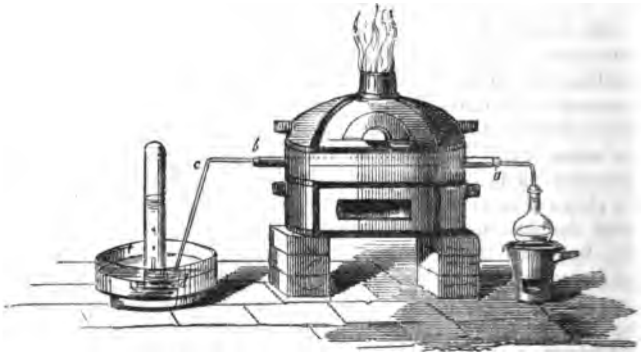
47. None of the metals commonly used in the arts have an attraction for oxygen sufficiently energetic to effect thus spontaneously the decomposition of water. The attraction, however, of some of them—iron, for example—may be so exalted by elevation of temperature that it may, by means of certain arrangements, produce a like effect.

An apparatus for the decomposition of water, by means of heated iron, is represented in fig. 4.

A porcelain tube, *a b*, the middle part of the length of which is filled with fragments of fine iron wire, is inserted across a furnace, by means of which the tube may be heated, so that the iron it contains shall be red-hot. One end, *a*, communicates by a rectangular tube with a glass vessel containing water, placed upon a charcoal fire, or supported over a spirit lamp. The other end, *b*, communicates by a bent tube, *b c d*, with a glass tube filled with water, inverted and immersed in a capsule or dish containing water. The water is supported in the tube, as in the former experiments, by the atmospheric pressure. If gas issue from the mouth of the tube, *d*, which is bent under that of the wide tube containing the water, this gas will rise in bubbles, displacing the water in the top of the tube.

These arrangements being made, and the iron contained in the tube, *a b*, being rendered red-hot, the water in the glass vessel is made to boil. The vapour proceeding from it entering the tube *a b* at *a*, forces its way through the interstices of the red-hot iron wire; there it is decomposed, the iron attracting the oxygen, with which it combines, forming a substance called the *oxide of iron*, which is familiarly known as *rust*. The hydrogen alone issues from the tube at *b*, and passing through *b c d* rises into the large tube, displacing the water, as represented in the figure.

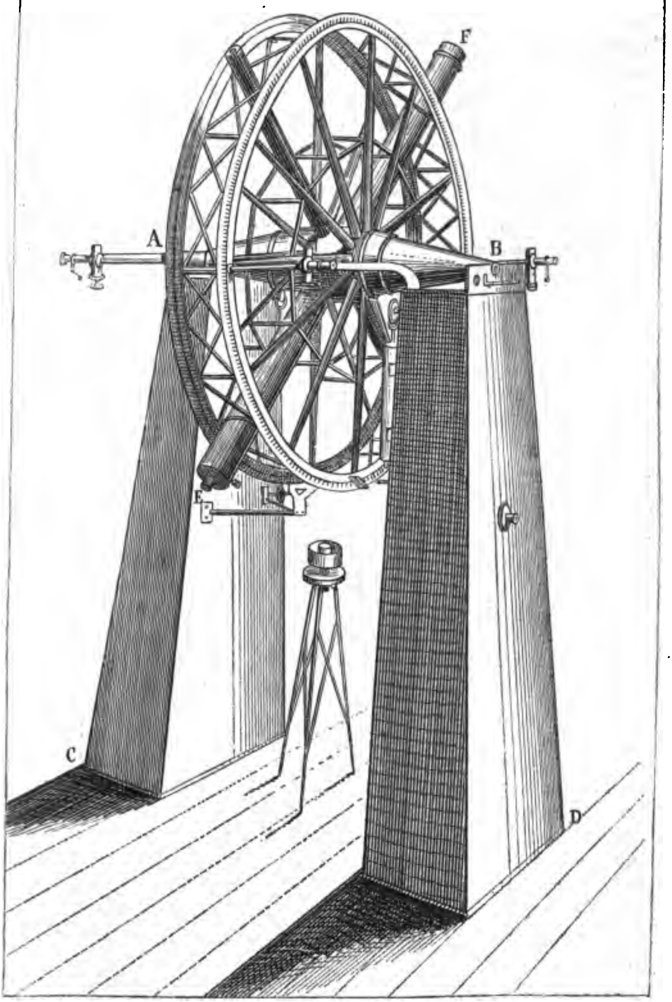
Fig. 4.



When a sufficient quantity of gas is collected, its weight is ascertained, and also the increase of weight imparted to the iron wire in the tube, *a b*, by the oxygen which has been combined with it, and it is always found that the latter is exactly eight times the former.

Thus we still find the same remarkable fact reproduced in various forms. The rusted wire is heavier than the original clean wire by the weight of the oxygen which it has attracted from the aqueous vapour, and which, combining with it, forms the rust; and this weight is eight times that of the hydrogen from which it has been separated, showing as before that water consists of 8 parts by weight of oxygen and 1 of hydrogen.

Fig. 1.



COMMON THINGS.

TIME.

CHAPTER I.

1. Simple notions difficult to define.—2. Conception of Time, how obtained. —3. By succession of sensible impressions.—4. Proof that such succession is necessary.—5. Time passes faster with some than with others.—6. Is measured only by a regular and uniform succession.—7. Periodic phenomena which may measure time.—8. Natural appearances intended for that purpose.—9. Significations of the word "day."—10. Hours.—11. Their length in certain cases variable.—12. Vulgar and equinoctial hours.—13. Commencement of the day with different nations.—14. Italian time.—15. Inconvenience of such a mode of reckoning.—16. Modern method.—17. Civil and astronomical time.—18. The day the standard unit. —19. Necessary to determine it rigorously.—20. What is a day?—21. Diurnal rotation of the heavens.—22. Its constancy and uniformity.—23. Nevertheless not fitted to be the unit of civil time. 24. The meridian.—25. Diurnal motion of the sun—means of observing it.—26. Transit instrument.—27. Method of observing with it.—28. Sidereal day—its subdivisions.—29. Its permanency and uniformity—unfit, nevertheless, for a measure of time.—30. Why the sun is not fit.

I.—TIME IN GENERAL.

1. THE most simple of our notions are those which it is most difficult to describe or define. It is fortunate that they are precisely those which least need definition. Geometers have failed in defining a straight line, or a plane surface, but no persons differ in their conceptions of the meaning of these terms. Locke observes, with his usual felicity and clearness, that a word which expresses a simple idea does not admit of definition, inasmuch as a definition being a sentence composed of two or more words having different significations, cannot collectively express one idea which has no composition at all. The only way to convey to the mind of another, the meaning of such a word, is by presenting to his senses the object or the quality which it expresses. In that case, if he possess the necessary organ of sense, he will immediately obtain the perception; if he do not all the words in the world will not convey it to him. A person blind or deaf from infancy can never acquire any perception of colours or sounds. A blind man after listening attentively to an elaborate description of the colour *scarlet*, declared that he had a very clear and satisfactory notion of it, and that he considered it like the *sound of a trumpet!*

2. Time is a word about the meaning of which it would seem that there could be no disagreement; yet we cannot as in the case of words expressing sensible ideas refer to any external object from which we can immediately receive the perception which that word expresses. Although we cannot define by words

the meaning of the terms white or red, we can point to the lily and the rose, and thus supersede verbal definition. We cannot define the notes of the nightingale or the lark, but if we walk forth in the night or at the early dawn, the one or the other will discourse music more eloquent than definition.

Can we then, by a like appeal to the senses, obtain a notion of what is expressed by the word TIME? Which organ does it address? Time cannot be seen, heard, felt, tasted or smelled. It cannot be seized and submitted to observation and analysis. It is the most fleeting of all perceptions. Moment follows moment in never ceasing succession, but no moment can be said to have any continued existence, so as to be submitted to contemplation.

3. Metaphysicians differ as to the mental process by which we acquire a perception of duration, but they agree generally that its origin is closely connected with the succession of our thoughts and ideas. From our observation and consciousness of this succession, and from that alone, does our original conception of time proceed. When the mind has once been stored with ideas and perceptions derived by the senses from external objects, the memory can at will reproduce them and marshal them in infinitely various series before the imagination. Of such succession of thoughts and feelings thus evoked by memory we are as distinctly conscious as we are of those derived directly from external objects, and by that consciousness we acquire a perception of time when no external objects are presented to the senses. Thus if during the darkness of night we lie awake, a constant succession of thoughts and images pass through the mind, consisting altogether of various ideas and combinations supplied by the memory. This succession of notions creates a consciousness from which we derive a perception of a certain lapse of time.

4. That an actual succession of thoughts, emotions, ideas or images, whether they proceed directly from external objects or arise from the operations of memory, reflection, or imagination, is absolutely necessary to our perception of time is demonstrated by the fact that whenever such succession ceases, our perception of time ceases with it. Thus in profound sleep without dreaming, we have no perception whatever of duration. Having gone to sleep at night, and waking, in the morning it is true that we know that a certain definite interval has elapsed, but we derive this knowledge by inference from external phenomena and not at all from consciousness. We see that the darkness of night has changed to the light of day; that the sun which was below the horizon is above it, and we know by past experience that these changes are only produced in a certain interval of time, and

that such interval of time must have elapsed since we fell asleep. But if we fall asleep in the evening and do not awaken until the next day but one, we are unconscious of the lapse of more than one night. Robinson Crusoe, alone on the desert island, being indisposed, swallowed a narcotic composed of rum and the infusion of tobacco, which threw him into a profound sleep that continued from the night until the afternoon of the next day but one, and he was unconscious of the lapse of more than a single night. He found accordingly, when liberated from his solitary abode, upon comparing his journal with the actual dates, that he had lost a day in his account.

5. It might, therefore, be naturally inferred that the succession of our thoughts or mental impressions, being the origin of our perception of duration, would be necessarily a measure of duration, and indeed the only measure of it. It is easy, nevertheless, to see that such an inference can only be admitted with considerable qualification. The succession of sensible impressions produced by certain regular and uniform series of external appearances is unquestionably an exact and the only exact measure of time, but it would be, on the other hand, a grave error to assume that such a just measure of duration can result indifferently from every series of mental impressions. Who does not know that a series of agreeable thoughts and brilliant ideas has the effect of making time pass with unwonted rapidity?

> "Too late I stayed. Forgive the crime!
> Unheeded flew the hours.
> How noiseless falls the foot of Time
> Which only treads on flowers!
>
> "Ah! who with clear account remarks
> The ebbing of his glass,
> When all its sands are diamond sparks,
> Which dazzle as they pass?"

Again,—the series of our thoughts becomes a most fallacious measure of time when we are the sport of the more exciting passions and emotions, such as hope, fear, or despair.

"*Rosalind.* Time travels in divers paces with divers persons; I'll tell you who time ambles withal, who time trots withal, who time gallops withal, and who he stands still withal.

"*Orlando.* I prythee, who does he trot withal?

"*Ros.* Marry, he trots hard with a young maid, between the contract of her marriage, and the day it is solemnised. If the interim be but a se'nnight, time's pace is so hard, that it seems the length of seven years.

"*Orl.* Who ambles time withal?

"*Ros.* With a priest that lacks Latin, and a rich man that hath not the gout: for the one sleeps easily, because he cannot study, and the other lives merrily, because he feels no pain; the one lacking the burden of lean and wasteful learning, the other knowing no burden of heavy tedious penury. These time ambles withal.

"*Orl.* Who doth he gallop withal?

"*Ros.* With a thief to the gallows: for though he go as softly as foot can fall, he thinks himself too soon there.

"*Orl.* Who stays it withal?

"*Ros.* With lawyers in the vacation: for they sleep between term and term, and then they perceive not how time moves."

SHAKSPEARE, *As You Like It*, Act III. Scene 2.

6. A succession of thoughts and perceptions floating at hazard through the mind, or excited casually and without regularity by external objects, produces a perception of time, but affords no measure of it; just as the general view of a landscape produces the impression of a certain progression of distances among the objects composing it, without, however, supplying the means of estimating with numerical precision such distances.

A progression of events or perceptions which would supply a measure of time, must be absolutely uniform and regular. In such case the number of repetitions of the same event or phenomenon found between any two points of the series becomes the measure of the interval of time which has elapsed between them.

7. The series of phenomena adopted by mankind as measures of time have been either natural or artificial. Natural measures of time consist of regularly recurring periodical phenomena, which are easily and universally observable by all the world, and which never cease to be reproduced with the same uniformity in all parts of the inhabited globe. Artificial measures are usually motions which are so contrived as to be uniform so long as they continue, and which, when exhausted, admit of being restored.

Any regular periodical change, however, may serve as a measure of time. Thus woodmen ascertain the age of certain trees by marks upon their trunks. The ages of certain species of cattle are indicated by the successive formation of rings on their horns. The age of horses is ascertained by the successive disappearance of marks from their teeth.

If a candle in burning were consumed uniformly its decrease of length might be used as a measure of time. In certain sales by auction, the continuance of the bidding was limited by "inch of candle."

8. But the periodical phenomena which have been most universally adopted in all ages and all countries as measures of time, are those which were expressly assigned for that, among many more important purposes, by the Omniscient, who, when he "made the firmament and saw that it was good," said—

"Let there be light in the firmament of the heaven, to divide the day from the night; and let them be for signs, and for seasons, and for days, and years:

"And God made two great lights; the greater light to rule the day, and the lesser light to rule the night."—Gen. i. 14, 16.

Days, weeks, months, and years, and the subdivisions of a day, hours, minutes, and seconds, having then been adopted by mankind in general as the measures of time, and as the landmarks of history and chronology, it may perhaps be thought that little more remains to be said about the matter; that these chronometric terms used in the common intercourse of life by all peoples—

> "Familiar in their mouths as household words,"

have significations so clear, distinct, and unequivocal as to supersede the necessity of all exposition and discussion. All the world knows what a day is, and that weeks, months, and years are composed of so many of these days. We shall, nevertheless, soon render it apparent that the import of these very familiar terms is not quite so clear even in the minds of moderately well-informed persons as it is supposed to be.

II.—THE HOURS.

9. The term DAY has two distinct significations. As opposed to night, it means the interval during which we receive light from the sun. Now this interval is not very definite. According to some, it means the interval between sunrise and sunset. But according to others, it signifies the interval between the morning dawn and the termination of the evening twilight; or from the disappearance of the stars before sunrise to their reappearance after sunset.

The other sense of the word DAY is that in which it is used as a chronometric term. It is the interval of time which elapses between two successive appearances of the sun at the same point of the heavens with relation to the horizon. This interval evidently includes a day and a night.

The Greeks used a word, for which there is no English equivalent, to express this latter sense of the term DAY. This word was νυχθήμερον (*nukthemeron*,) a compound of the terms night and day.

10. From time immemorial a duodecimal division of the day has been adopted by all nations. Some peoples have counted the hours consecutively, from one to twenty-four. Others have divided the day into two series of twelve hours. It may perhaps be a legitimate subject of regret that the same system of decimal reckoning, which has conferred such simplicity upon the arithmetical

notation and terminology, should not have been applied to the counting of time. When the spirit of innovation was in the ascendant in France in 1793, such an attempt was made, the day being divided into ten hours, the hour into an hundred minutes, and the minute into an hundred seconds. The power of custom, however, prevailed over even the domination of terrorism and the project signally failed.

11. The hours into which the day was resolved were generally intended to be equal, each being the twenty-fourth part of the entire interval called a day. Nevertheless, there were some exceptions to this. Thus, at a certain epoch in Greece, the interval between sunrise and sunset was divided into twelve equal parts called hours of the day, and the other interval, between sunset and sunrise, was also divided into twelve equal parts, called hours of the night. It is evident that the diurnal hours were equal to the nocturnal hours only at the equinoxes, and that from the spring to the autumnal equinox the diurnal were longer than the nocturnal hours, and from the autumnal to the spring equinox the nocturnal were longer than the diurnal hours. The hours, both diurnal and nocturnal, were also subject to continual variation of length. From the first day of winter, or the shortest day, to the first day of summer, or the longest day, the diurnal hours constantly increased, and the nocturnal hours constantly decreased in length; and from the first day of summer to the first day of winter, the nocturnal hours constantly increased, while the diurnal hours constantly diminished.

Such a system could not be properly denominated chronometric at all, since the interval of time called an hour was different at different seasons.

12. Defective as such a method of counting time must have been for the purposes of common life, it was utterly inadmissible for any scientific investigations; and Ptolemy, in his astronomical observations, was always obliged to transform the vulgar hours into equinoxial hours; so called, no doubt, because it was only at the equinoxes that the vulgar diurnal were equal to the nocturnal hours.

How imperfect the art of measuring time was in that age, may be imagined when it is stated that, in the observations of Ptolemy, the time of astronomical phenomena is never indicated nearer the truth than a quarter of an hour. At present it is determined in good observations to less than the tenth of a second.

13. For chronometric purposes, it is not enough to fix the value of the standard unit of time. It is necessary also to establish a convention as to the moment at which each successive unit commences, and the preceding one terminates. In a word, a point of

departure must be agreed upon for each chronometric unit; and this, as will be seen, is a subject upon which much disaccord has prevailed, and the establishment of which, with all the aids afforded by the advanced state of astronomical science, has been a matter of the greatest difficulty and delicacy.

The Jews, the ancient Athenians, the Chinese, and other Oriental nations, as well as the Italians, fixed the commencement of the day at sunset. According to the Italians, even to the present times, the day is divided into twenty-four successive hours, reckoned continuously from sunset to sunset. Thus, at an hour before sunset, it is said to be twenty-three o'clock, at two hours before sunset it is twenty-two o'clock, and so on.

According to this system, the hour of sunrise varies from day to day, and from season to season, but the hour of sunset is constant, being 24 o'clock or 0 o'clock. At the equinoxes, the sun rises at twelve o'clock. From the spring to the autumnal equinoxes, it rises before twelve, and from the autumnal to the spring equinoxes, it rises after twelve.

It is evident that a clock to indicate such time must be set from day to day, or at least from week to week, since the hour of sunset would be constantly later during one half-year, and constantly earlier during the other.

14. At some places in Italy, and more particularly at Rome, public clocks are set according to this system, and others placed near them according to the common system, the indications of the one being called ITALIAN, and those of the other, FRENCH TIME.

The system of Italian time has been defended upon the ground of the convenience it affords, of always telling the hour of sunset, so as to show to travellers and those who are occupied in out-door employments the time they have at their disposition before nightfall. Against this convenience, such as it is, however, is to be considered the constant necessity from day to day of setting all the watches and clocks—an operation called by the Italians TOCCARE IL TEMPO—to touch the time. There are other obvious inconveniences, however, attending such a system, such as the constant variation of the hours of meals, of going to bed and rising, of all descriptions of regular labour, the hours of opening and closing all public offices, of commencing and terminating all public business, &c. Nevertheless, such is the force of established custom, that this mode of reckoning time still prevails to a great extent in the Italian peninsula.

The Babylonians, Syrians, Persians, the modern Greeks, and the inhabitants of the Balearic Isles, took the moment of sunrise for the commencement of the day.

15. Whether the commencement of the day be fixed at sunset

or sunrise, the disadvantages indicated above must attend such a mode of reckoning time; to which it may be added, that of all diurnal phenomena, there is not one of which the observation is attended with more uncertainty and risk of error than sunrise and sunset.

16. The English, French, Germans, and generally the moderns in all the more civilised parts of the globe, commence the day at midnight, and divide it into two equal series of twelve hours, so that midday is twelve o'clock as well as midnight. According to this system of reckoning, it is necessary, whenever an hour is named, to indicate its relation to noon. The hours before noon are indicated by the letters A.M., and those after noon by P.M., being the initials of the Latin words *ante meridiem* (before midday), and *post meridiem* (after midday).

Among ancient astronomers who adopted this mode of reckoning, may be mentioned Hipparchus, who flourished about a hundred and fifty years before our era, and among moderns Copernicus.

The ancient Egyptians began the day at noon, in which they were followed by Ptolemy, a celebrated astronomer, who flourished at Alexandria in the second century of our era. This diurnal epoch has been by general consent adopted by modern astronomers, who divide the day into twenty-four successive hours, reckoned from noon to noon. Thus, according to their manner of reckoning, twenty minutes and an half after ten o'clock in the morning, would be $22^h\ 20^m\ 30^s$.

17. Civil or common time, therefore, is half a day before astronomical time, a circumstance which must always be carefully allowed for in the comparison of dates expressed according to the two modes of reckoning.

Thus, for example, the first day of the year 1854, according to civil reckoning, commenced at the moment of midnight, between the 31st December, 1853, and 1st January, 1854. But according to astronomical reckoning it commenced at midday on 1st January, 1854. It follows, therefore, that the twelve hours which preceded the noon of 1st January, 1854, were according to astronomical reckoning the last twelve hours of the year 1853.

In like manner, a certain hour of the forenoon, 5 A.M. of a day (Tuesday, for example), according to civil time, is $17^h\ 0^m\ 0^s$ of the preceding day (Monday), according to astronomical time. From noon, however, till midnight of any given day, the civil and astronomical dates are exactly the same.

III.—THE DAY.

18. A day then being adopted by common consent, and indeed by the force of things, as the standard unit for the measure of

time, all longer intervals being expressed by its multiples, and all shorter ones by its fractional subdivisions, it is above all things indispensable that its absolute length should be understood with perfect clearness, and ascertained with the most rigorous precision. Like all standard measures, it is necessary that it should have one invariable length, and that this length should be at all times capable of verification by comparison with some natural phenomena, observable at all times and places, and which, during an endless succession of ages, past and future, is subject to no change.

19. It may perhaps be thought that such extreme precision and permanency is needless, and that a departure of the standard from exactness by a very minute fraction would be for all practical purposes unimportant. If the standard, whatever it be, were only applied to the measurement of quantities which are not large multiples of itself, this might be admitted. But it is otherwise, when it forms a very minute fraction of that which it is applied to measure. An error of the ten-thousandth part of an inch in a foot may be unimportant, so long as short spaces—as, for example, the length of a room—only are in question. But, if we attempt to apply the foot to measure great distances, the small error is multiplied until it swells into one so great as utterly to vitiate the results. Thus an error of the ten-thousandth part of an inch in a foot becomes an error of more than an inch in two miles; of more than a foot in twenty-four miles; of more than a mile in 120000 miles, and so on.

If in the measurement of distance vast errors may thus arise from the indefinite increase of small inaccuracies of the standard units by multiplication and accumulation, it is much more so with respect to the measures of time, errors in which, even of the smallest amount, accumulating for ages, would involve not only astronomy but history and chronology in complete confusion. It will therefore be understood how important it is in many points of view, that we should obtain clear, distinct, and settled notions of the import of these terms,—days, weeks, months, and years,—which constitute our chronometric nomenclature.

20. What is a day, the fundamental unit of all time? In a rough and general way we have defined it to be the interval of time which elapses between two successive returns of the sun to the same point of the firmament. But to observe and ascertain with the necessary precision this interval, it is necessary to have some means of marking a certain point of the firmament; and, when so marked, of observing the exact moment at which the sun arrives at it. The sun, however, not being a mere point, but a circular space or *disc*, as it is called, of considerable apparent

magnitude, covers a certain part of the heavens, and different points of this disc arrive at a given point of the firmament at different moments; so that when we speak of the moment the sun passes any given point of the heavens, our words have no definite meaning unless we specify what point of the sun's disc our observation is applied to. The point in question is of course the centre of the disc, the successive returns of which to a certain position in the heavens must be observed.

The point most convenient in all respects for such an observation is the highest to which the sun rises in its diurnal course across the heavens. But to render this position of the sun's centre, and the means of observing it intelligible, it will be necessary to consider the apparent diurnal motion of the heavens under a much more general point of view.

21. If we suppose an observer to stand with his back to the north, looking to the south, and consequently having the east upon his left, and the west upon his right, the sky being supposed to be cloudless for a day and a night, a remarkable spectacle will be presented to his view, the imposing grandeur of which continues to excite our admiration in spite of the familiarity which is produced by its never-ceasing presence.

The celestial vault presents the appearance of a vast hollow sphere, one half of which only is presented at any one moment to our view, the base of this visible hemisphere being the plane of the horizon, in the centre of which we stand. This hollow sphere appears to have a motion of rotation round a certain diameter as an axis, carrying with it as it revolves the countless objects, stars, planets, sun, and moon, which appear in various positions upon its stupendous concave surface. Standing in the position here described the sphere seems to revolve from left to right round an axis inclined to the horizon in a vertical plane, directed north and south. This apparent motion causes all the celestial objects to rise in succession on the left, that is on the east, and gradually rising they approach to and pass the vertical plane directed north and south, and after passing it, they descend upon the right, that is on the west, and in fine disappear below the horizon.

22. This diurnal motion of the celestial sphere is characterised by the most rigorous and absolute uniformity and constancy. It is never faster, never slower, and never stops. It has continued thus to move from time immemorial, and according to all appearance, and subject to the existing laws of nature, will continue so to move as long as the globe of the earth endures.

23. Such constancy and uniformity, combined with the fact that it is universally observable, would render such an apparent motion eminently fitted as a measure of time. Nevertheless as

will presently appear, it is attended with other circumstances which make it unsuitable for that purpose.

24. The vertical plane directed north and south, of which we have spoken, if supposed to be extended upwards to the firmament, will meet the visible hemisphere in a semicircle which, passing through the zenith, as the point directly over the observer is called, descends to the horizon at the north and south points. This semicircle is called the MERIDIAN. It divides the visible hemisphere into two equal parts, the eastern on the left of the observer, and the western on his right. By the diurnal rotation of the celestial sphere, all objects upon it rising in the east ascend to the meridian, where they attain their greatest altitude, and then descend to the west and disappear. The interval during which each of them is visible is divided into two exactly equal parts by the meridian, the time which elapses between the moment at which it rises and that at which it passes the meridian and attains its greatest altitude, being equal to that which elapses between the latter moment, and that at which it disappears.

This movement of the heavens is more observable by night than by day, because it is then shared by a vast number of objects, having positions infinitely various upon the celestial vault. Countless numbers are every moment rising or ascending towards the meridian, passing it, or descending from it, or setting. Although the objects upon the firmament by day are not less numerous, they are rendered invisible by the superior splendour of the sun. They may nevertheless be seen even then with sufficiently powerful telescopes, and they present exactly the same apparent motion, being still carried round with the common motion imparted by the celestial sphere.

25. The sun like the rest is carried round with the diurnal motion, and its continuance above the horizon is divided into equal parts by the meridian. Hence it appears that when its centre is on the meridian, it is midday or noon, and at that moment it has its greatest altitude.

This moment then being the epoch upon which the fundamental unit of time is based, it becomes of great importance to comprehend the means which have been contrived for accurately observing it. If the meridian were traced by a visible line upon the heavens, the observation of the moment at which any celestial object crosses it would be easy. But that not being the case, it may be asked how the moment at which the sun's centre passes a merely imaginary line, can be ascertained with the extreme precision necessary in this case.

26. Astronomers have accomplished this by a very simple and

admirable contrivance. They have enabled observers to mark for themselves the meridian upon the firmament with such distinctness and precision, that the moment at which any celestial object passes it can be ascertained to a small fraction of a second by direct observation.

One of the forms of instrument most easily understood by which this is accomplished is shown in fig. 1 (p. 113). The passage of any celestial object across the meridian being called a TRANSIT, instruments adapted to ascertain the moment such transits take place are called TRANSIT INSTRUMENTS. The particular form shown in fig. 1 is called a TRANSIT CIRCLE.

The instrument is mounted on two pillars, A C and B D, of solid stone, erected on a foundation of masonry presenting all the conditions necessary to guarantee the greatest firmness and solidity. These pillars stand east and west, the space between them therefore, looking north and south. A telescope E F is supported upon an horizontal axis A B, the ends of which rest in angular-shaped supports, called from their form Y's, which are established upon the summits of the two stone pillars. These supports being rendered by suitable adjustments truly horizontal, and the line joining them being directed truly east and west, the telescope when placed in an horizontal direction will point exactly north and south, and if it be turned upon its axis, so as to be successively directed to different points of the firmament, it will sweep over the celestial meridian.

Attached to the telescope is a graduated circle, consisting of two flat rims of metal, connected together in a firm manner by a system of spokes and diagonal braces. By means of this circle the altitude of any object to which the telescope may be directed can be measured; but this not being connected with our present purpose need not be further noticed. All that is now necessary to be understood is that when it is turned upon its axis, the telescope is successively directed to all points of the meridian.

When we look through the telescope, we behold a circular space upon the heavens of a certain magnitude. This space is called the FIELD OF VIEW.

The meridian is in the direction of a line which would pass vertically through the centre of this circular space, dividing it into two equal parts, one to the right, and the other to the left. The celestial objects, as they are carried by the diurnal motion of the sphere, pass from east to west across the meridian, moving in a direction apparently horizontal. Such of them, therefore, as may come within the limits of the field of view, in any one position of the telescope, will appear to pass across the field in horizontal lines; and if the observer were provided with any means of ascertaining the moment at which an object is precisely half-way between the point at which it enters and that at which it leaves the field of view, he would know the moment at which it passed the meridian.

This is accomplished by a very simple and admirable contrivance. In the eye-piece of the telescope is fixed a small frame, across which are extended vertically five or seven fine wires or filaments at equal distances apart, the centre one passing through the middle of the field of view, and one horizontal wire also passing through the centre, and therefore dividing all the vertical wires equally.

The field of view and the system of wires are shown in fig. 2, (p. 129), where E W is the horizontal, and N S the middle vertical wire. It must be observed that the wires are so extremely fine that even when they are magnified by the eye-glass of the telescope they still appear like mere hairs. The number of vertical wires being always odd, one of them will necessarily pass through the centre. The instrument represented in fig. 1 is provided with such adjustments, that the middle wire N S, can be brought to coincide with the utmost precision with the meridian.

The magnifying power of the telescope has the same effect upon the apparent motions of objects as upon their apparent magnitude. It increases the one in the same proportion as the other. The consequence is that, although the apparent diurnal motion of celestial objects is no more perceptible to the naked eye than is the motion of the hour-hand of a watch, yet when viewed with the telescope, this motion is very distinctly perceptible. The stars seem like so many luminous insects, creeping with a visible motion across the field in horizontal directions, and passing in succession behind each of the parallel vertical wires.

27. So rapid is this apparent motion of the celestial objects across the field of the telescope, that a star is seen to pass from one side to the other of one of the vertical wires between two successive beats of the clock. Thus it may be seen at *o*, fig. 2, at the moment marked by one beat, and at *o′*, at the moment marked by the next. Practised observers are in such case able to determine to the tenth of a second, or even less, the instant of its transit over the wire. Thus if the moment it is at *o*, be $10^h\ 20^m\ 20^s$, and that at which it is at *o′*, be $10^h\ 20^m\ 21^s$, the observer will be able to say for example that the instant at which it has passed the wire N S is more than $10^h\ 20^m\ 21^s{\cdot}4$, and less than $10^h\ 20^m\ 21^s{\cdot}5$, and he may assign the time as $10^h\ 20^m\ 21^s{\cdot}45$. Different observers acquire, according to their respective aptitudes, different degrees of skill in such observations, and in all cases the results of their observations can be checked by comparing those obtained

by two or more observers observing the same transit at the same place.

28. If the transit of the same star be observed for two or more successive nights, the interval which elapses between any two successive transits can thus be determined. Now it has been found that this interval is absolutely the same, not only for all stars whatever, but also that it is the same at whatever part of the earth the observation may be made. By comparing the results of ancient with modern observations, it has also been found that this interval has not undergone the least change.

It is well known that this apparent diurnal rotation of the heavens, by which a common motion is thus imparted to all celestial objects, is the optical effect produced by the rotation of the earth upon its axis, and the time of that rotation is consequently the interval which elapses between two successive meridional transits of any fixed star.

Such is the constant and invariable character of this motion, and its absolute uniformity, that Laplace has shown, independently of all theory, that, as a matter of fact, the time of this apparent rotation of the heavens cannot have suffered any change amounting to so much as the hundredth part of a second since the time of Hipparchus, being an interval of twenty centuries.

This interval is called a SIDEREAL DAY.

The sidereal day is subdivided into hours, minutes, and seconds, in the manner already explained.

The circumference of the celestial sphere being supposed to be divided into 360°, through which it revolves in 24 hours, it follows that it turns through 15° per hour, 15′ per minute, and 15″ per second.

It is perhaps to be regretted that the terms minutes and seconds have been used in two different senses, the more especially, as their application in both these senses is constantly necessary in all astronomical works. As applied to the arcs of circles, or to angular measurement, a MINUTE signifies the sixtieth part of a degree, and a SECOND the sixtieth part of a minute. As applied to time a MINUTE signifies the sixtieth part of an hour, and a SECOND the sixtieth part of a minute.

The confusion which might arise in calculations in which both time and angular measures are involved, is prevented by the adoption of the letters ^{m} and ^{s}, to express minutes and seconds of time, and the signs ′ and ″ to express angular minutes and seconds. Thus— $8^{h}\ 30^{m}\ 25{\cdot}6^{s}$

expresses an interval of time consisting of 8 hours, 30 minutes, 25 seconds, and 6-tenths of a second; while

$$8^{\circ}\ 30'\ 25{\cdot}6''$$

expresses an angle or circular arc, the magnitude of which is 8 degrees, 30 minutes, 25 seconds, and 6-tenths of a second.

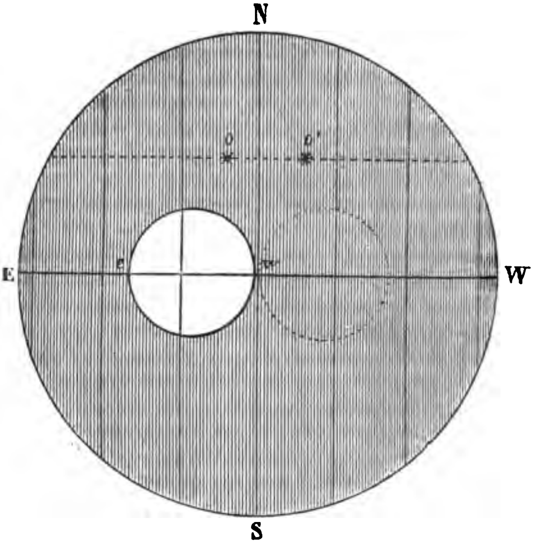
29. The absolute uniformity and permanency which thus characterise the diurnal rotation of the heavens, combined with the fact that it is observable at all parts of the earth, would render it eminently suitable as a measure of time. It wants, nevertheless, one condition which is quite as essential for the purposes of civil life as uniformity and permanence. It is not marked and limited by any conspicuous phenomena which strike the senses of all mankind. It does not correspond with the periodical returns of light and darkness, nor with the successive returns of the sun to the meridian. It does not even fall into accordance with the conspicuous lunar phenomena; so that, although it be true that it is observable alike in all parts of the earth, the phenomena by which it is marked are such as can only be observed with the aid of astronomical instruments, and such as do not address themselves to mankind in general.

30. To obtain, therefore, a fit measure of time for civil purposes, some measure must be found which will fall into such accordance with the periodical vicissitudes of light and darkness and the successive meridional transits of the sun, that the chronometric unit may correspond either exactly, or nearly enough, for all practical purposes with those diurnal appearances by which the records of mankind have in all ages and countries been made.

And why, it may naturally enough be asked, may not the successive returns of the sun to the meridian serve the purpose?

It may be stated briefly but distinctly that the solar diurnal phenomena, as they are actually presented in the heavens, do not answer as a measure of time even for civil, to say nothing of scientific purposes. Why they are unsuitable, and what substitute has been contrived for them, will require some words of explanation.

Fig. 2.



COMMON THINGS.

TIME.

CHAPTER II.

31. How to observe the sun's transits.—32. Interval between them variable. —33. Mean and apparent time.—34. Relative changes of mean and apparent time.—35. The days on which they coincide.—36. The Equation of time.—37. Further explained.—38. Its extreme error.—39. Mean time adopted in France.—40. Unfitness of apparent time.—41. Local time varies with longitude.—42. Equalisation of local time proposed.—43. How time-pieces are regulated.—44. Mean solar hours, minutes, and seconds.—45. Length of sidereal day.—46. The week.—47. Opinions as to its origin.—48. Both opinions erroneous.—49. Origin of the names of the days.—50. First day of the week.—51. The month.

31. The sun presenting to an observer not merely a brilliant point, as is the case with a fixed star, but a circular luminous space called a disc, of considerable magnitude, the various parts of which pass the meridian at different moments of time, it is

necessary to define what is meant by the meridional transit of the sun with more precision, and to show by what sort of observation the moment of such transit can be ascertained.

It has been agreed, that by the meridional transit of the sun, that of the centre of the solar disc is to be understood. But as this centre is not marked by any visible or observable point by which it can be distinguished from other points of the sun's disc, its transit cannot be directly observed.

The difficulty arising from this circumstance has been overcome by a very simple expedient.

As the solar disc enters the field of view from the east side it approaches gradually the meridional wire, N S, and at length touches it, as shown in fig. 2, with its western edge, W, or LIMB, as it is called by astronomers. The moment of this contact is observed in the manner already described in the case of a star. The solar disc then continues to move across the field until it takes the position indicated by the dotted circle, in which the eastern limb touches the meridional wire, N S. The moment this takes place being also observed, the middle of the interval is calculated, which is the instant at which the centre of the disc passed the meridian.*

32. If the sun were stationary in the firmament, it is evident that the interval between its successive meridional transits would be the same as that of the successive transits of a fixed star, and in that case the SIDEREAL DAY would be identical with the SOLAR DAY. But it is well known that the sun is not thus fixed. On the contrary, it moves constantly in the firmament, making a complete circuit of the heavens in a year. If this motion were uniform, the daily displacement of the sun would be 0° 59′ 8·2″.

Now let us consider what effect such a displacement, being always eastward, would produce upon the interval between the successive transits of the sun compared with that of the transits of a star which suffers no such displacement.

Let *s* (fig. 3) represent the sun at the moment its centre is on the meridian, N S, on any given day, and let *o* represent a fixed star which is on the meridian at the same instant. After the lapse of 24 sidereal hours the star, *o*, will be again upon the meridian, N S; but during these 24 hours the sun, *s*, will have moved towards E, that is, eastward to the position, *s′*, the distance, *s s′*, being

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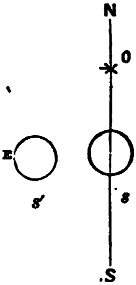
* In fig. 2 the motion of the celestial objects and their position is represented as they are seen by the naked eye, or by a terrestrial telescope. But all objects are inverted and reversed by the astronomical telescope, so that the top is seen at the bottom, and the east seen at the west, and *vice versâ*. It has been thought better for the present purpose to represent the points and motions as they are naturally seen.

0° 59′ 8·2″. The sun, therefore, will not yet have come to the meridian, and will not arrive at it until it is carried by the diurnal motion of the firmament through this space of 0° 59′ 8·2″. But since the firmament moves at the rate of 15′ in each minute of time, it will take 3^{m} 56^{s} to carry the sun, *s′* to the meridian. It follows, therefore, that, supposing the sun to move daily 0° 59′ 8·2″ eastward at right angles to the meridian, a solar day would exceed a sidereal day by 3^{m} 56^{s}.

Fig. 8.



If the eastward daily motion of the sun, measured at right angles to the meridian, were uniform therefore, the interval between its successive transits would possess all the requisites for a chronometric unit, and although the solar day would not be equal in length to the sidereal day, it would, nevertheless, be of invariable length, and would besides be in complete accordance with those periodical vicissitudes of light and darkness which have been, by common consent, used by mankind in all countries and in all ages as the measures of time.

But the solar day is wanting in fact in this essential condition; it is not invariable in length. Its variation, though not great, is nevertheless such as to render it unsuitable as an unit of time, even for civil, to say nothing of astronomical, uses. No clock or watch could be constructed which would continue to go with the sun. A clock, which at one time of year would correspond with the meridional transits, would at another either anticipate them, or fall behind them.

The variation in the rate at which the sun is displaced daily towards the east, and at right angles to the meridian, arises from several causes. *First*, the rate at which the sun moves upon the firmament is subject to variation. While its average daily displacement is, as we have stated, 0° 59′ 8·2″, it amounts at the beginning of the year to 1° 1′ 9·9″, and at the middle of the year to only 0° 57′ 11·5″. Although we are not directly concerned here with the cause of this variation, it may be as well to observe, that it arises from the fact that the earth does not revolve in an exact circle with the sun in the centre, which it must have done if its motion were uniform, but in an oval, the sun being nearer to one end than to the other, and the rate of the motion increasing as the distance of the sun decreases. *Secondly*, the motion of the sun is not generally at right angles to the meridian, but more or less oblique to it at different seasons, and the more oblique it is to the meridian, the less does a given displacement affect its eastward motion at right angles to the meridian. *Thirdly*, the sun is at different seasons at different distances from the celestial equator, and the more remote it is from the equator the more does a given displacement affect its return to the meridian, for the same reason exactly as that for which two places on the earth, at a given distance east and west of each other, will have a greater difference of longitude the farther they are from the line.

33. Seeing, then, that the interval between the successive meridional transits of the sun is subject to variation, and therefore unsuitable for a chronometric unit, but that it would be suitable if the sun's daily easterly displacement were always the same, astronomers have imagined an expedient, which, without sacrificing the advantage of an accordance with the periodical vicissitudes of light and darkness, secures the advantage of complete uniformity as to the length of the chronometric unit.

This is accomplished by the substitution for the real of a fictitious sun, whose daily easterly motion is always the same, and exactly equal to the average daily easterly motion of the real sun, that is, to 0° 59′ 8·2″. The time, as indicated by this fictitious sun, is called MEAN TIME, the moment when its centre passes the meridian is called MEAN NOON, and the fictitious sun itself is sometimes called the MEAN SUN.

The variable and unavailable time indicated by the motion of the real sun is called APPARENT TIME, and the moment of the meridional transit of the real sun is called APPARENT NOON.

34. From what has been stated, it will therefore be understood that the mean and the real suns make a complete circuit of the heavens in exactly the same time, that is, in a year; so that, starting together from a given point, they will arrive together at the same point at the instant which terminates the year; but while the easterly daily displacement of the one is always absolutely the same, being 0° 59′ 8·2″, that of the other is variable, being sometimes greater than 0° 59′ 8·2″, sometimes less, and at certain times the same.

To illustrate the changes of the relative position of the two suns, let us imagine two railway trains to start from London at the same moment, side by side, on two lines of rails, making a trip to Liverpool and back, and to arrive at London, on their return, precisely at the same moment; but let the speed of one be absolutely uniform, at 30 miles an hour, during the entire journey, while that of the other is subject to variation, being slower in ascending inclines, and faster in descending them. The latter will at some places outstrip, and at others fall behind, the former, and at certain points they will be for a moment side by side. The variable train will represent the real, and the uniform train the fictitious or mean sun.

The two trains throughout their trip would, in such case, never be found very far asunder. Neither will the two suns separate to any great distance. If they did so, the expedient of the fictitious sun as a measure of time for civil purposes would fail, inasmuch as the civil day would fall into perceivable disaccord with the real day.

35. The days of the year at which the true and fictitious suns come together, and on which the mean and apparent time agree, are subject to a very slight variation; but in the year 1855, this coincidence takes place on the 15th April, 15th June, 1st September, and 24th December.

To trace the relative positions of the mean and real suns, we are to consider that on the 15th April they are on the meridian together, or very nearly so. The next day the mean sun will have passed to the east of the real sun, so that the latter will arrive at the meridian first, and when the mean sun comes upon the meridian, that is, at the moment of mean noon, the real sun will be to the west of it. Each succeeding day the real sun will fall back more and more to the west of the mean sun, and the apparent noon will precede the mean noon by a constantly increasing interval. Thus, on the 16th April, the apparent precedes the mean noon by 8^s, on the 17th by $22{\cdot}4^s$, on the 18th by $36{\cdot}4^s$, on the 19th by 50^s, and so on; this gradual increase going on until the 15th May, on which day the apparent precedes the mean noon by $3^m\ 53{\cdot}87^s$, and the distance of the true sun, west of the mean sun, is then $58'\ 28''$, a space equal to nearly twice the apparent diameter of the sun.

After the 15th May the real sun falls less and less west of the mean sun, so that the two suns approach each other closer and closer until the 15th June, when they again coincide. Thus, from the 15th April to the 15th June, the apparent time precedes the mean time by a quantity which varies from 0 to $3^m\ 53{\cdot}87^s$, and the distance of the real sun to the west of the mean sun varies from $0°$ to $58'\ 28''$.

As the time shown by the mean sun is the time shown by a properly regulated clock, it follows that during this interval the sun passes the meridian before noon—a fact which is commonly expressed by saying that the sun is FAST.

36. The interval of time between the meridional transits of the real and fictitious suns, or what is the same, the interval between the apparent noon and the mean or civil noon, or the noon shown by a properly regulated clock, is called the EQUATION OF TIME.

37. Between the 15th April and the 15th June it appears, therefore, from what has been explained, that the time of mean noon can be deduced from that of apparent noon by subtracting

from the latter the equation of time, and on the other hand, the time of apparent noon is deduced from that of mean noon by adding to the latter the equation of time.

But to trace further the relative positions of the true and mean suns. After the 15th June the real sun falls to the east of the mean sun, and consequently does not come to the meridian until after the mean sun has passed it, that is, until after noon. On the 16th June the real sun passes the meridian 13·53^{s} later than the mean sun; on the 17th, 26·43^{s}; on the 18th, 39·42^{s}; on the 19th, 52·44^{s}; and so on, passing it each day later and later in the afternoon, until the 26th July, when it passes the meridian 6^{m} 12·68^{s} later. After that day, it begins to pass the meridian at earlier intervals after the mean sun, and the intervals become less and less until the 1st September, when it coincides with the mean sun.

On the 26th July the apparent noon being 6^{m} 12·68^{s} later than mean noon, the centre of the real sun must be 1° 33′ 10·2″ east of the centre of the mean sun, which is a space equal to about three times the apparent diameter of the sun.

Thus it appears, that from the 15th June to the 1st September, the apparent time follows the mean or civil time, that is to say, the sun passes the meridian at times varying from 0 to 0^{h} 6^{m} 12·68^{s} in the afternoon. This fact is usually stated by saying that the sun is SLOW.

During this interval the apparent time is found by subtracting the equation of time from the mean time, and the mean time by adding it to the apparent time.

After the 1st September the real sun again passes to the west of the mean sun, and consequently passes the meridian before it.

Thus, on the 2nd September, its meridional transit takes place at 19·68^{s} before noon; on the 3rd at 38·77^{s}; on the 4th at 58·11^{s}; and so on, the transit being earlier and earlier until the 3rd November, when it takes place at 16^{m} 18·51^{s} before noon, which is therefore the greatest amount of the equation of time, and the greatest departure of the time of the sun from the time of the clock. The sun is in this case 16^{m} 18·51^{s} fast.

38. Since the firmament moves at the rate of fifteen minutes of arc for every minute of time, it follows that in 16^{m} 18·51^{s} before the meridional transit of the sun, its departure from the meridian must amount to 4° 4′ 37·65″, a space equal to nearly eight times the sun's apparent diameter.

From the 3rd November to the 25th December the distance of the real sun west of the mean sun constantly decreases, and they coincide on the 25th December.

It follows, therefore, that from 1st September to the 25th

December, the sun is fast by an interval which varies from 0 to $16^{\mathrm{m}}\ 18{\cdot}51^{\mathrm{s}}$.

After 25th December the real sun once more falls to the eastward of the mean sun, and consequently it does not arrive at the meridian until after the mean sun has passed it, that is until some time after the mean noon. On the 26th December it passes the meridian at $40{\cdot}45^{\mathrm{s}}$; on the 27th at $1^{\mathrm{m}}\ 10{\cdot}15^{\mathrm{s}}$; on the 28th at $1^{\mathrm{m}}\ 39{\cdot}71^{\mathrm{s}}$ after noon, and so on, the lateness of its transit increasing until the 11th February, 1856, when it passes the meridian at $14^{\mathrm{m}}\ 32{\cdot}36^{\mathrm{s}}$ after noon. After this its transit is less and less late until the 15th April, when it again coincides with the mean sun.

It appears, therefore, that from the 25th December to the 15th April the sun is always slow, its deviation from the time of the clock being greatest on the 11th February, when it amounts to $14^{\mathrm{m}}\ 32{\cdot}36^{\mathrm{s}}$. The distance of the true sun from the mean corresponding to this interval, computed as before, is 3° 38′ 5·4″. On the 11th February, therefore, the true sun is at this distance east of the mean sun. This distance is not quite seven times the diameter of the sun's disc.

39. The real interval between two successive transits of the sun being variable, it is evident that no piece of mechanism could be constructed which, without adjustment, would point daily to 12 o'clock at the moment of apparent noon. So long, therefore, as the mean time was not adopted as the chronometric measure for civil purposes, it was necessary daily, or at least weekly, to regulate all the clocks, public and private, according to the varying time of apparent noon. This was the practice even in a country so enlightened as France until an epoch so recent as 1816. Before this time the most remarkable disagreement constantly prevailed among the public clocks of Paris, few of which were regulated sufficiently often by observations of the sun. M. Arago relates, that Delambre, the celebrated French astronomer, told him that he frequently heard the public clocks, one after another, striking the same hour during half an hour.

At the time of introducing the change in the regulation of the clocks of Paris from apparent to mean time, the prefect of the Seine (which is the title of the chief of the municipality, or mayor of Paris,) entertained such serious fears that an insurrectional movement might be excited among the working classes, who, it was supposed, would revolt against a noon which did not correspond with the noon of the sun, or mid-day, and which consequently would divide the day, from sunrise to sunset, into two unequal parts, that he refused to sign the *ordonnance* for the change unless it was accompanied by a formal report of the Board of Longitude to sanction it. These apprehensions, however, proved groundless, for the change took place unperceived by the great mass of the people.

Meanwhile the watch and clockmakers rejoiced at the change which established a sort of civil time, in accordance with which it was mechanically possible to construct timepieces. Such a change relieved them from the annoyance produced by the remonstrances of their customers complaining of their best constructed watches losing or gaining as much as a quarter of an hour, or even more, upon the sun. It was in vain that the celebrated Breguet, and his colleagues of the trade, assured them that the sun and not the watch was too fast or too slow.

40. It may be easily imagined how utterly incompatible with the management of public business as now conducted such an imperfect system of chronometric regulation would be, when it is considered what disastrous consequences might arise upon railways, if the starting, stopping, and arrival of trains, were not subject to greater precision than could be attained under such circumstances.

41. However exactly the chronometric measures in a given place may be regulated, their indications will necessarily differ from those of similar chronometric measures in other places having different longitudes. The cause of this difference is the successive arrival of the mean sun at the several meridians of such places. By the apparent diurnal motion of the heavens, the sun, carried round the globe, arrives in succession, from hour to hour, at the meridians of places situate one westward of the other, and as the sun thus carried round makes a complete revolution in 24 hours, it moves from meridian to meridian at the rate of 360° in 24 hours, or 15° per hour, or 1° in four minutes. Thus, at two places differing in their longitude by 1°, the local time will differ by four minutes, that which is east being four minutes earlier than that which is west.

In consequence of this the clocks in different towns of the United Kingdom show at the same moment of absolute time different hours. Liverpool, for example, being 3° west of London, and 1° being equivalent to four minutes, it follows that the sun passes the meridian of London twelve minutes before it passes that of Liverpool; and as this is equally true of the fictitious sun which regulates civil time, it follows that mean noon at London, and therefore all other hours determined with relation to mean noon, precede the corresponding hours at Liverpool by twelve minutes.

42. It has been lately proposed to assimilate the chronometric epochs at all parts of the United Kingdom, by means of clocks which are moved with a common motion, so that their hands,

however distant they may be one from another, must always point at the same moment to the same hour. Such a common motion may be imparted to them by means of an electric current transmitted along conducting wires, similar to those used for the electric telegraph. In this way all clocks in all parts of the kingdom could be made to indicate the Greenwich time.

If this measure should be adopted the civil time will have undergone another change, and instead of being the mean time proper to the place, it will be the mean time at Greenwich. Thus the civil time at Liverpool, for example, would differ from the mean time there by twelve minutes. And as the mean time at certain epochs already differs from the apparent time by more than a quarter of an hour, it will sometimes happen that the civil time will differ from the apparent time by nearly half an hour. Thus the sun may be on the meridian of Liverpool, and consequently the real mid-day may take place at about half-past eleven o'clock.

Such a circumstance, however contradictory and anomalous it may appear when considered astronomically, would, however, be attended with no inconvenience in civil life.

43. The length of a mean solar or civil day, and the method of defining the moment of its commencement, being well understood, it remains to show how the motion of a timepiece is regulated so as to represent it.

Let us suppose a clock, the pendulum of which is intended to beat seconds, to be roughly regulated, so that its hour-hand shall make two complete revolutions in a day. This approximation to an exact movement may be easily accomplished by many obvious expedients, one of which would be to set it to twelve o'clock when the sun appears to have attained its greatest altitude.

The clock, thus approximately regulated, being placed near a transit instrument, such as that already described (26), let the observer, as the sun approaches the meridian, direct the telescope to the point of the meridian over which it is about to pass. When the disc of the sun enters the field of view, and is approaching the wire, N S, fig. 2, let the observer look at the clock, and observe the exact time, and let him count the time from that moment by his ear as he listens to the successive beats of the clock. Continuing thus to count, he will find that the western edge of the sun's disc will touch the wire N S at a certain moment between two successive beats, and by practice he will be able to assign the moment of contact between the beats. As the disc of the sun takes about two minutes to pass across the wire, he will have sufficient time to write down the exact time of the transit of the western edge and to return to the telescope before the eastern edge comes near the wire. Again observing the time shown by the clock, and again counting the beats he observes, in like manner, the moment at which the eastern edge touches the wire.

Now let us suppose the times of contact to be as follows:—

	H.	M.	S.
Contact of Western limb	12	10	$8\frac{3}{10}$
Contact of Eastern limb	12	11	$59\frac{5}{10}$
	24	22	$7\frac{8}{10}$.
Transit of sun's centre	12	11	$3\frac{9}{10}$

As has been already explained, the time of the transit of the centre of the sun's disc is found by adding together the times of the transits of the eastern and western limbs, and dividing the sum by two.

It would then appear from this that the time shown by the clock at the moment of apparent noon is eleven minutes and three seconds, and nine-tenths of a second after twelve.

Let us suppose that the observer then refers to the table of the equation of time for the day of the observation, and finds there that the moment of mean noon was $3^{m}\ 32\frac{1}{10}^{s}$ earlier than the apparent noon. To find the time of mean noon, therefore, as shown by the clock, he performs the following arithmetical operation:—

	H.	M.	.
From apparent noon	12	11	$3\frac{9}{10}$
Subtract the equation of time		3	$32\frac{1}{10}$
	12	7	$31\frac{8}{10}$

From which it appears that the clock is $7^{m}\ 31\frac{8}{10}^{s}$ fast.

Leaving the clock unaltered, the same observations and calculations are made the following or any succeeding day, and if the clock gives a later hour than $12^{h}\ 7^{m}\ 31\frac{8}{10}^{s}$ for mean noon, its rate is too fast, or it "gains." If it gives an earlier hour, its rate is too slow, or it "loses." Let us suppose, for example, that after the lapse of five days the clock gives $12^{h}\ 8^{m}\ 25\frac{3}{10}^{s}$ for mean noon, we shall have

	H.	M.	S.
Mean noon—sixth day	12	8	$25\frac{3}{10}$
,, first day	12	7	$31\frac{8}{10}$
Clock gains in five days	0	0	$53\frac{5}{10}$

The clock therefore gains at the rate of $10\frac{7}{10}$ seconds per day.

The method of correcting the rate is by lengthening the pendulum, as will be explained in a future number of the MUSEUM.

44. When the pendulum has been exactly regulated, it will swing 86400 times between the moments of mean noon on two successive days. The time of 60 swings will be a mean solar minute, and the time of 3600 will be a mean solar hour. The clock thus regulated, being set to 12 at the moment of mean noon, will again point to 12 at mean midnight, and again at the succeeding mean noon, and so on.

45. From what has been explained, it will be understood that a sidereal day, or the time of the rotation of the earth upon its axis, is somewhat shorter than a common civil day. The exact proportion between these chronometric units, which is by no means an easy problem, has, however, been solved by astronomers, and it is found that 100,000000 common or civil days are equal to 100,273791 sidereal days, or, if less extreme arithmetical precision be sufficient, it may be stated that in a thousand common days the earth makes $1002\frac{3}{4}$ rotations on its axis.

From these numbers it is easy to express the time of rotation in hours, minutes, and seconds of civil time. To do this we have the proportion

100,273791 : 100,000000 : : 24 : the time of rotation.

By the rule of three, therefore, the time of rotation will be

$$\frac{\overset{\text{hours.}}{2400,000000}}{100,273791} = 23^{\text{h}}\ 56^{\text{m}}\ 4{\cdot}09^{\text{s}}.$$

It appears, therefore, that the time of the earth's rotation falls short of 24 hours, such as those shown by well regulated clocks, by three minutes, fifty-five seconds, and ninety-one hundredths of a second.

IV.—THE WEEK.

46. Having thus explained fully the meaning of a day, considered as the standard unit of time, and of the subordinate and lesser divisions of hours, minutes, and seconds, it will now be necessary to notice the larger chronometric units.

The chronometric unit, in the ascending order, which comes next to the day, is the WEEK.*

47. The opinions of historians and antiquarians are much divided as to the date and prevalence of the custom of counting time by periods of seven days. It is certain, however, that among the oriental nations such a period has been in use from time immemorial. Philo Judæus, Josephus, and St. Clement of

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* From the Saxon word WEOC, having the same signification.

Alexandria, maintained that the period of a week was in use among all ancient peoples. Goguet, a modern French authority, adopts the same opinion. Others, on the contrary, among whom may be mentioned Costard and Maury,* contend that no ancient use of the period of seven days prevailed except among the Jews, who took it of course from the traditions of the creation, given in the Pentateuch.

48. Both these extreme opinions, but especially the latter, are erroneous. The week, as a division of time and multiple of a day, was in general use among the ancient Chinese, the Egyptians, the Chaldeans, and the Arabs, as well as among the Jews. It was not in the calendar of the Greeks, who divided the month into three periods of ten days, and it was not adopted by the Romans until the time of Theodosius, who reigned in the latter part of the fourth century of our era. There is properly no word in the Latin classics equivalent to the term WEEK. *Hebdomas* signified seven of anything, and when applied to days had reference to diseases, in which the physicians held (as now appears erroneously) that crises were manifested of which the periods were 7, 14, and 21 days.

While most authorities trace the use of weeks to the Mosaic account of the creation, others ascribe it to the phases of the moon, and others again to the planets as known to the ancients. The lunar phases not being even nearly commensurate with the week, they can scarcely be regarded as the origin of this chronometric unit, and the denomination of the days having in all languages more or less reference to the celestial objects, the latter opinion seems to be most generally entertained.

49. In the ancient Egyptian astronomy, the sun and moon being included among the planets, and of the bodies properly called planets, five only being known, Mercury, Venus, Mars, Jupiter, and Saturn, the total number of planets was taken to be seven. They were ranked in the order of their supposed distances from the earth as follows:—

1. SATURN
2. JUPITER
3. MARS
4. THE SUN
5. VENUS
6. MERCURY
7. THE MOON.

Dion Cassius, an eminent historical writer of Rome, who was consul about 220 A.D., gives the following explanation of the manner in which the Egyptians derived the names of the days of the week, and their order, from those of the seven planets.

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* See dissertation by M. Biot upon the astronomical chronology.—Mem. Acad. Sc. tome xxii.

THE WEEK.

The series of HOURS without reference to days were resolved into periods of seven, each dedicated to a planet. Thus the first hour was dedicated to SATURN, the next to JUPITER, the third to MARS, and so on. The day, however, being divided into twenty-four hours, which is not a multiple of seven, it followed necessarily that each successive day would begin with an hour dedicated to a different planet. Let us see then how the days would, according to such a system, succeed each other.

The day which begins with the hour dedicated to Saturn would evidently end with the hour dedicated to Mars, for the twenty-four hours would consist of three complete periods of seven, and the twenty-fourth hour would be the third of the fourth period and would consequently be the hour dedicated to Mars. The first hour of the next day would be that dedicated to the Sun. In like manner this day beginning with the hour dedicated to the Sun, and consisting of three hours more than three complete periods, would end with the hour dedicated to Mercury, and the next day would begin with the hour dedicated to the Moon.

The succeeding day would in like manner commence with the third in order from the Moon, that is, Mars; the next with the third in order from Mars, that is Mercury; the next with the third in order from Mercury, that is Jupiter; the next with the third in order from Jupiter, that is Venus; and after Venus the series would recommence with the hour dedicated to Saturn.

Thus in each successive period of seven days, the first hour of each successive day of the period would be dedicated to the planets in the following order:—

1. SATURN
2. THE SUN
3. THE MOON
4. MARS
5. MERCURY
6. JUPITER
7. VENUS.

The Latin names of the days are in accordance with this,

1. DIES SATURNI (Saturn's day)
2. DIES SOLIS (Sun's day)
3. DIES LUNAE (Moon's day)
4. DIES MARTIS (Mars' day)
5. DIES MERCURII (Mercury's day)
6. DIES JOVIS (Jupiter's day)
7. DIES VENERIS (Venus' day).

These names are retained in the English language for SATURDAY, SUNDAY, MONDAY. The names for the days dedicated to Mars, Mercury, Jupiter, and Venus have been taken from Saxon divinities.

The days of Mars, Jupiter, and Venus have been called TUESDAY, THURSDAY, and FRIDAY, from TUESCO, THOR, and FRIGGA, the Mars, Jupiter, and Venus of the Scandinavian mythology. The day of Mercury has been called WEDNESDAY, from WODIN or ODIN, the chief of the gods.

In all legislative and judiciary acts and documents, the Latin names of the days of the week are still retained.

Derivations of the Latin names, with one or two exceptions, are used in the languages of Western Europe. SUNDAY is an exception, the name of which is a derivative of DIES DOMINICA, the LORD'S-DAY, and SATURDAY, in Italian, is SABBATO, the SABBATH, that day being the Jewish Sabbath.

There is another method of connecting the series of days of the week with the seven celestial objects from which their names have been taken, so as to explain the order in which they succeed each other, which if it be only from respect to its antiquity may be worth mentioning here.

The ancient astrologers, among whom were included a large number of astronomers, properly so called, imagined a mystical figure, in the centre of which the earth was placed, surrounded by the seven celestial bodies dividing the circular space as shown in fig. 4, into seven equal arcs. From each planet's place two straight lines were supposed to be drawn to the places of the two most remote planets in the circular order, so as to form seven triangles, each of which has two rectilinear sides and an arc of the circle as its base. The planets succeed each other round this circle in the order of their then supposed distances, in the same manner as already explained. Thus Saturn is succeeded by Jupiter, which is followed by Mars, and so on as in the former case.

Now let us suppose that commencing from any one planet, the moon for example, we follow in regular succession the intersecting straight lines, we shall find that the planets succeed each other in the same order as that of the days of the week, or in the contrary order. Thus proceeding from A, we pass to B, from B to C, and so on, following the course indicated by the arrows, and the names of the planets at A, B, C, D, E, F, and G are precisely those from which the names of the days of the week, beginning from Monday and ending with Sunday, are taken. If we had followed the other course against the direction of the arrows, we should have obtained the names in a contrary order, as if we went backwards through the week.

In the cabalistic doctrines of astrology there were various influences imputed to the succession of planets thus obtained, with which we have however here no concern.

In both systems the number seven which forms the basis of the chronometric period of a week had its origin in the supposed number of the planetary bodies. This number seven was in other respects regarded by the ancients as being invested with various mystical influences, and as being reproduced in forms infinitely various, not only in the natural objects and phenomena, but even in human events. There were the seven stars, the seven cardinal sins, the seven wonders of the world, the seven critical days in human maladies, the thrice seven years which converted a youth into a man, and so on. In short the number seven was regarded with a sort of religious veneration, so that the announcement of an eighth or ninth planet in Egypt, Greece, or Rome would, as Arago wittily observed, have been regarded as such a heresy as to bring upon the unhappy discoverer the maledictions of the priests and even the punishment of death instead of the honours and rewards of academies and universities.

50. The week being an arbitrary and conventional chronometric period, having no relation to any natural phenomenon, the day which begins it is equally so. In the Hebrew Scriptures its origin being connected with the narrative of the creation, and the institution of the Sabbath being a perpetual commemoration of the succession of divine acts by which the present state of the earth and the creatures which inhabit it were called into being, the seventh, or last day of the week, would naturally be that upon which the Sabbath is celebrated, and according to this principle Sunday would be the last and Monday the first day of the week. Such, however, has not been the conventional arrangement. The Sabbath, or seventh-day of the Jews, was the morrow of the Crucifixion, and was Saturday; the succeeding day being that of the Resurrection, was consequently the first day of the Jewish week.

Among Christians, this first day has accordingly been celebrated as Sunday, or the day of rest and prayer, the Jews still of course observing Saturday as their Sabbath.

It has therefore been generally agreed to call Sunday the first day of the week, but to invest it with those sacred attributes and characters which in the fourth commandment were conferred upon the seventh day.

V.—THE MONTH.

51. The next chronometric unit is the month, a name which implies some correspondence with lunar phenomena. The relation of this division of time to the moon is apparent in all languages. Thus, while in Greek *μην* (mēn) is *month*, *μήνη* (mēnē) is *moon*, both being derived from the Sanscrit MÂ, *measure*, the Persian MÂH signifying also *month*.

The sun and moon move round the celestial sphere in the same direction from west to east, but the moon moves more than thirteen times faster than the sun, and consequently makes more than thirteen revolutions of the heavens while the sun makes one. The moon is therefore constantly either departing from or approaching to and overtaking the sun. At the moment it overtakes the sun it is said to be in CONJUNCTION, and is called NEW MOON. At the moment it is in the opposite part of the heavens, and when therefore it is 180° removed from the sun, it is in opposition; and as it then presents its enlightened hemisphere directly towards the earth, it appears with a complete circular disc, and is called FULL MOON. When it is a quarter of the heavens, or 90°, before or behind the sun, it is said to be in the QUARTERS, and appears as an enlightened semicircle, and is called HALF MOON.

The time which the moon takes to make one complete revolution of the heavens, is called the moon's "period," or "periodic time," and is found by the most exact modern observations to be

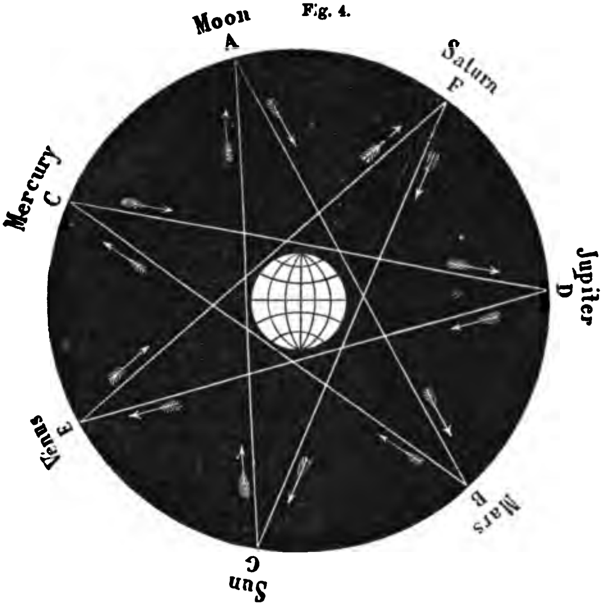
$$27{\cdot}32166 \text{ days}$$

expressed in decimals. If expressed in hours, minutes, and seconds it is

$$27^{d}\ 7^{h}\ 43^{m}\ 11\tfrac{4}{10}{}^{s}.$$

The moon's period is unsuitable for a measure of civil time for two reasons: first and chiefly because the moment which terminates one period and begins the next, is not marked by any conspicuous and generally observable phenomenon, and can only be ascertained by astronomers; and secondly, because it is incommensurable with the fundamental chronometric standard, the day, and as will hereafter appear, equally so with the year. For these reasons it has never been adopted as a chronometric unit either for civil or astronomical purposes.

Fig. 4.



COMMON THINGS.

TIME.

CHAPTER III.

The month (continued).—52. Not conformable with lunar periods.—53. Difficulty of subdividing the year.—54. Division unequal.—55. Egyptian months.—56. Greek.—57. Solon's months.—58. Roman months. —Romulus.—59. Origin of names of months.—60. Additional months of Numa.—61. Origin of their names.—62. Their lengths.—63. Superstition in favour of odd numbers—methods of remembering the lengths of the months.—64. Calends. — 65. Greek Calends.—66. Nones.—67. Ides.—68. Practice of counting backwards.—69. Discordance of the Roman year with the seasons.—70. Month Mercedonius.—71. Legal meaning of "month."—72. The year.—73. What is a year?—74. Egyptian.—75. Only a rude approximation to the course of the seasons.—76. The vague year and Sothic period.—77. Advantage of Egyptian year.—78. Greek year.—79. Meton and his cycle.—80. Origin of Golden Number.—81. Meton ridiculed by Aristophanes.—82. Near accordance of the lunar phases with the Metonic cycle.—83. Roman year.—84. Pontifical abuses.—85. Julian Calendar. —86. Bissextile years.

THE interval between two successive conjunctions of the moon with the sun, or between two successive new moons, is greater than the moon's period. If we suppose the sun and moon to start together from conjunction, the moon moving more than thirteen times faster, immediately goes before the sun; and as the sun moves at the rate of about 1° per day, the moon must move at the rate of more than 13° per day, and consequently departs from the sun at the rate of more than 12° per day. When the moon has made a complete revolution, that is at the end of 27·32166 days from conjunction, the sun will have advanced about 27° from the place at which the moon arrives after having completed its revolution. The next conjunction or new moon cannot take place therefore until the moon overtakes the sun, and as it advances upon the sun at the rate of a little more than 12° per day, it will take somewhat more than two days to come up with it. In fine, by the most exact observations and calculations, it has been found that the interval between two successive conjunctions is

29·530589 days

expressed decimally, or in hours, minutes, and seconds

$29^d\ 12^h\ 44^m\ 2{\cdot}89^s$.

This interval is called a LUNATION, and it exceeds 29½ days, as it appears, by a little less than three quarters of an hour.

Although the lunation is not commensurable with either the day or the year, yet its recurrence, and even its fractional parts, are marked by phenomena so striking and so universally observable without instruments, that in all ages and all countries it has by common consent been used to measure time, the fractional parts by which it exceeds 29 and falls short of 30 days, being compensated by various expedients.

The evident object to which the adoption of months was directed was to establish a convenient chronometric unit, holding an intermediate place between the week and the year; such unit to consist of a complete number of days without a fraction, and to be at the same time an exact submultiple of the year; that is, such an interval that the year should be an exact multiple of it, and finally that it should be in as near accordance as might be found practicable with the period of the lunar changes.

That various nations in different ages should be found in complete disaccord in their attempts at the satisfaction of these several conditions, and that the usages and chronological forms into which these attempts resolved themselves should exhibit much confusion, will not be at all surprising when it is considered that the conditions themselves are not only incompatible one with another, but their satisfaction utterly impracticable.

These conditions involve the consideration of three distinct chronometric periods, the diurnal, the lunar, and the solar or annual. The lunar period, whatever be the phenomena on which it is based, whether it be the actual time of the revolution of the moon round the earth, or the interval between its phases, that is between full moon and full moon, is neither a multiple of the day nor a submultiple of the year. A month therefore, determined by the lunar period in whatever way it be considered, could not consist of an exact number of days, nor be so taken that the year should consist of an exact number of months.

52. All real conformity therefore between the chronometric periods derived from the sun and moon must very soon have been found to be unattainable, and the problem was therefore limited to the establishment of a convenient subdivision of the year, holding a place between the day and the year, dividing the year into an exact number of equal parts, which should be neither too great nor too small for social convenience.

53. Now let us consider how far these several conditions were attainable.

A year, as will presently appear, consists of 365 days *and a fraction*. In its chronological effects this fraction is attended with many inconveniences of its own, but we shall for the present disembarrass ourselves of it and consider the year as the ancients did, to consist of the round number of 365 days.

This number is somewhat unmanageable when the object is to resolve it into equal parts, each of which shall be a whole number. It is divisible without a remainder by 5 and by 73, but by no other whole number.

It follows from this that the year admits of only two subdivisions fulfilling the prescribed conditions. It may be divided into 73 intervals of 5 days, or into 5 intervals of 73 days.

The former subdivision being less than a week, would be obviously inadmissible. By the latter the year would consist of 5 equal divisions of 73 days.

Would such a division fulfil the conditions? Would it be too great for social convenience?

The most conclusive practical answer to this question may be derived from the concurrent testimony of all nations sufficiently advanced to know that the year consists of 365 days. It must have been evident that a division into 5 equal periods of 73 days could be made. Nevertheless no such division of the year was ever proposed. By this common consent therefore such a subdivision has been tacitly but unequivocally pronounced to be unsuitable to the purposes of mankind.

54. Seeing then that no division of the year into equal periods was practicable, two expedients only were presented; *first*, to

divide the year into a certain number of *equal* parts, with a remainder, and to count that remainder as a supplemental part, just as in arithmetic, when the dividend is not exactly divisible by the divisor, we give the quotient, and name the remainder; or, *secondly*, to resolve the year into some convenient number of *unequal* parts, which would be effected by distributing the days composing the remainder between the equal divisions obtained by the former expedient.

Both of these expedients have accordingly been adopted by different nations in different ages, but the latter has eventually received the general preference, and the year is now, by all the more civilised nations of the world, divided into twelve unequal parts, called, somewhat inappropriately, MONTHS.

55. The Egyptians, adopting the first of the expedients above stated, divided the year into twelve equal months of thirty days. The remaining five days formed a complementary division at the end of the year, and were intercalated before the commencement of the next year.

56. The division of the year into months by the Greeks was not only incongruous and obscure, but no two states of the confederation agreed either in the number, or the lengths, or the names of their months, nor even in the beginning of their year. Generally, however, all agreed in resolving the year into twelve months of unequal lengths. Some states commenced the year at the summer solstice, some at the winter solstice, and some at or near the autumnal equinox. A dozen or more separate states called the months by different names. Some months were designated by specific names, while others were indicated only by their numerical order, counting from the beginning of the year; but as the states did not begin their years from a common epoch, months having the same numerical designation in different states corresponded to different seasons. Thus, the fifth Attic month corresponded with November, the fifth Lacedemonian with February, the fifth Bœotian with May, the fifth Delphic with January, and so on. The enormous confusion which must arise from such discordance between different provinces of a nation, having the same language, and the numerous and perplexing difficulties of interpretation of Greek authors, writing according to such different customs, can be easily imagined.

We forbear to encumber our pages with the eleven series of names of these months, which, being all obsolete, would have no other utility than to aid the interpretation of the Greek authors. Those who desire such information, will find sufficient for their purpose in the "Dictionary of Greek and Roman Antiquities" of Dr. Smith, Art. Calendarium.

THE MONTHS.

57. Notwithstanding the discordancy and obscurity which surround the records and usages of the Greeks, in relation to their calendar, their knowledge of the period of the lunar phases which served as the basis of their chronometric system, attained at an early epoch of their history extraordinary precision. The lunation was estimated at 29½ days, which is within three quarters of an hour of its exact length, and it was assumed as their month. Solon went even so far as to make the month exactly conformable to it. The thirtieth day was divided between two successive months; the first half, from sunrise to sunset, being given to the expiring month, and the other from sunset to sunrise to the new month. The day thus shared betweon two different months was called ἕνη καὶ νεα, the *old and new* day. This correction, however, was only applied to every other month, the intermediate months being limited to twenty-nine days.

At a later period, when this had fallen into disuse, the same name, ἕνη καὶ νεα, was applied to the last day of the month generally.

58. If any evidence were sought to illustrate the difficulty which has attended the attainment of a degree of perfection in the art of counting and recording time, it would be found in a review of the state of that art among the Greeks and Romans, the two most enlightened and civilised nations of antiquity, to whose labours in literature and the sciences the moderns are so largely indebted.

Nothing that can be imagined can exceed the confusion and absurdity which prevailed in the Roman chronometric conventions before a very late period in the progress of the empire.

Romulus, the founder of Rome, established a year, consisting of ten months, six of which had thirty, and four thirty-one days, making the year 304 days.

Since the names given to these months have, for the most part, come down to modern times, and have been adopted in our own nomenclature, it will be useful here to state them, and notice their origin.

The first four months of the year of Romulus were called, MARS, APRILIS, MAÏA, and JUNIUS, from whence our names MARCH, APRIL, MAY, and JUNE.

59. The first took its name from Mars, the father of Romulus, according to the Roman fable.

The origin of the second is somewhat uncertain, some deriving it from the Latin word *aperire*, to *open*, allusive to the state of vegetation in spring; and others from *Aphrodité*, one of the Greek names of Venus.

The names of May and June were taken obviously enough from Maïa, the mother of Mercury, and Juno, the queen of the gods.*

The names of the other six months, expressing merely their numerical order, were—

Quintilis (the fifth)
Sextilis (the sixth)
September (the seventh)
October (the eighth)
November (the ninth)
December (the tenth).

60. A year of 304 days could not long endure, since it would be soon thrown into discordance with the nature of things. It was, accordingly, no later than the succeeding reign, that of Numa, that two months were added to the year. These were called JANUARY and FEBRUARY.

In the first instance, February stood before January, the former being put at the end, and the latter at the beginning of the year. This order was, however, subsequently reversed, and January remaining the first month of the year, February became the second, March being the third, and so on. This will explain a circumstance, which often excites inquiries in relation to the last four months of the year, which appear to hold an order in the series of months different from that indicated by their names. It must be remembered, that when they received their names March was the first month.

61. JANUARY, the first month of the year, took its name from JANUS, a divinity who held an important place in the Roman religion. Janus presided over the beginning of every thing; he was the guardian deity of gates, and was represented with two faces looking to opposite sides. He was on this account selected to preside over the first month.

FEBRUARY took its name from FEBRUUS, an ancient Italian divinity, whose rites were celebrated during the latter part of that month. This divinity also presided over the dead, whose festival, called FERALIA, was celebrated about the same time.

At a later period, the names of the months QUINTILIS and SEXTILIS were changed to those of JULIUS and AUGUSTUS, to commemorate these Emperors, the former of whom, as we shall see, was signalised by a most important reform of the methods of recording time. These names are continued by us for the months of July and August.

Such was the origin of the present names of the twelve months of the year.

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* Ovid gives a different derivation of the names of May and June—namely, that they are the months of the old (majores) and young (juvenes)

"Tertius a senibus, juvenum de nomine quartus."
Fasti, Book I. line 41.

62. Unequal as were the lengths of the months instituted by Romulus, still greater inequality, irregularity, and confusion, were introduced by his successors. In the Romulian year of ten months, the months of March, May, Quintilis (afterwards July), and October, had each thirty-one days, all the others having thirty. When it was decided to render the year more conformable to the solar phenomena, by increasing its length, it was resolved to add fifty-one days to it; but this being considered too much for one month, and too little for two, one day was taken for each of the six months having thirty days; and the fifty-seven days thus obtained were divided into two months, twenty-nine being given to January, and twenty-eight to February.

The months then stood as follows:—

	Days.		Days.
January	29	July (then Quintilis)	31
February	28	August (then Sextilis)	29
March	31	September	29
April	29	October	31
May	31	November	29
June	29	December	29

The practice of such arithmetical caprices in dealing with matters upon which all chronological and historical records must more or less depend, would seem inexplicable if tradition had not supplied a clue to it. Why, for example, take a day from each of the months of thirty, instead of the obvious expedient of taking the *odd day* from each of those having thirty-one days?

63. It appears that in these times odd numbers were regarded as *lucky* or auspicious, even ones *unlucky* or inauspicious. A point was therefore made to create divisions of time, consisting, as far as possible, of odd numbers of days! Months of twenty-nine and thirty-one days were, therefore, preferable to months of thirty days. Fifty-one days being added to 304, gave a year of 355 days, which, being an odd number, answered very well. But it was impossible to divide an odd number into twelve parts, all of which are odd, since twelve odd numbers added together would make an even number. One of the twelve months was doomed, by the very nature of things, and the laws of number, to consist of an even number of days. This unlucky number was, therefore, as a matter of course, assigned to February, over which the Genius of Death presided, and which was appropriated to the celebration of the Festival of the Dead. Hence it arose that February has the exceptional number of twenty-eight days.

Before we hastily visit with harsh censure this most absurd superstition, let us pause, and look at home, and see if we be ourselves totally exempt from ideas altogether as absurd, if not quite as mischievous. Who has not met with persons professing some claims to education and intellectual position, who object to a dinner party composed of thirteen, and to an odd number of candles being lighted on certain occasions? How many who would consider themselves insulted if they were charged with ignorance, object to start upon a journey, or to commence any serious enterprise on a Friday?

The difficulty of recollecting which months have thirty-one and which only thirty days, has been so generally acknowledged, that various technical aids to the memory have been contrived by which they may be at any moment ascertained.

If the months be reckoned in numerical order from the beginning of the year, the odd months, as far as the seventh, and the even ones afterwards, are those which have thirty-one days. Thus, they are the first, third, fifth, seventh, eighth, tenth, and twelfth, which are January, March, May, July, August, October, and December.

When we close the hand there are four projecting knuckles of the four fingers, with depressions between them. If we give the knuckles and intermediate depressions the names of the successive months, recommencing from the first knuckle, after having once gone over them, we shall find that the months of thirty-one days are those which fall upon the knuckles. Thus, the knuckle of the first finger is January, that of the second March, that of the third May, and that of the fourth July. Recommencing then, that of the first is August, that of the second October, and that of the third December.

Every one is familiar with the lines—

"Thirty days hath November,
April, June, and September;
February hath twenty-eight alone,
And all the rest have thirty-one."

64. The first day of a month was called by the Romans CALENDS, a name which was also applied to the months themselves. Hence it came that a table, showing for the current year the succession of months, and of the days in each month, came to be called a CALENDAR.

65. The name Calends was not used by the Greeks. Hence arose a saying when any thing was indefinitely adjourned, that it was postponed to the "Greek Calends."

66. The seventh days of the four great months, as those consisting of thirty-one days were denominated, and the fifth days of all the lesser months, consisting of twenty-nine days, were called NONES.

67. In like manner, the fifteenth days of all the great months, and the thirteenth of all the lesser months were called IDES.

68. The cause of this difference of position of the ides and nones in the greater and lesser months is to be found in the Roman custom of counting time *backwards*. Thus, in all months, greater or lesser, the ides were the seventeenth days, and the nones the twenty-fifth days, counting backwards from the last day inclusive.

It was not only the nones and ides themselves that were counted backwards, but also the intermediate days. Thus, in a month of thirty-one days, the first six days were called successively as follows:—

1st day . . .	Calends
2nd ,, ...	Sixth before the nones
3rd ,, . . .	Fifth ,, ,,
4th ,, ...	Fourth ,, ,,
5th ,, . . .	Third ,, ,,
6th ,, ...	The eve of the nones
7th ,, . . .	The nones.

In the same manner, the days succeeding the nones were counted backwards from the ides, and those succeeding the ides counted backwards from the calends of the next month.

Although carried to such an extent, the practice of backward reckoning was absurd; the method is, in certain cases, obviously convenient, and is still in general use. When remarkable festival days and anniversaries occur, we all find it convenient to name the preceding day their *eve*, and we even sometimes refer to the second or third day before such or such a remarkable epoch.

69. The periodic returns of the seasons taking place at intervals of about 365 days, could not remain long in accordance with a year of 355 days. This was soon perceived; and of all the inexplicable expedients of which the management of chronometric regulation affords any example, certainly the most curious by far was that by which it was attempted to bring the civil into accordance with the natural year.

Imperfect as the knowledge of astronomy was in these times, the mere observation of the returns of the seasons, such as all agriculturists in the rudest state would have made, was enough to show that 355 days was ten or twelve days less than the period of the seasons; and, therefore, that by continuing to count time by such a year, the seasons would return ten or twelve days later from year to year.

70. Numa, the successor of Romulus, who, as has been already stated, modified the calendar, decided that the civil year should be brought into accordance with the period of the seasons, by introducing into every other year a thirteenth month, called

Mercedonius, consisting alternately of twenty-two and twenty-three days. So far the expedient presented nothing very singular, but the manner in which this supplemental bi-annual month was introduced was most curious. It was decreed that the progress of the month of February in every other year should be suspended at the end of the twenty-third day, and that then the month Mercedonius should commence, and that, when it was completed, the month of February should be continued to its last day! Thus Mercedonius was wedged in between the 23rd and 24th of February. In these alternate years, the day after the 23rd February was the 1st Mercedonius, and the day after the 22nd or 23rd Mercedonius, as the case might be, was the 24th February, and the succeeding days the 25th, 26th, 27th, and 28th of February!!!

71. The term month has been used in different senses, one of which is the interval during which the moon makes a complete revolution round the earth.

Four weeks exceeding this interval by no more than sixteen hours, that period of time has been also called a month. According to Blackstone, this is the legal sense of the term, unless a different meaning be expressly given to it. A lease for twelve months is a lease for forty-eight weeks.*

VI.—THE YEAR.

72. This is the largest of the chronometric units, and is consequently that by which all long periods are expressed.

73. What is a YEAR? To most persons it may seem that such a question is superfluous, forasmuch as every one must very well know what a year is. If we press for an answer, and sift such as are given, the matter will not, however, prove to be so plain and so easy.

Some may reply that it is the interval of time during which the sun makes a complete revolution of the heavens.

Others will say that it is the interval determined by the periodical recurrence of the seasons.

The question would be stripped of part of its difficulty if these two intervals were the same. But they are not. If it be replied that their difference is not great, we may rejoin that the difference, however small it may be, will become great by accumulation, and that when the question relates to centuries it may be such as to throw the two definitions into utter discordance.

In explaining the circumstances attending the diurnal unit, we showed that one essential condition attending it was, that it should be invariable; in other words, that every succeeding day should have exactly the same length. The same condition is indispensable; and for the same, and even stronger, reasons in the case of the annual unit. Yet the natural standard from which that unit is taken, the periodical return of the seasons, like the periodical return of the sun to the meridian, is subject to a certain variation. It is on that account unsuitable for a standard measure of time. This defect, however, is removed by an expedient similar to that by which the mean solar day was substituted for the apparent solar day. A fictitious period is assigned to the return of the seasons, which is a mean between the extreme variations of the actual period which marks their successive returns, and this fictitious period, which is invariable and never differs much from the real period, being sometimes a little more and sometimes a little less, is adopted as the chronological year.

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* Blackstone, ii. chap. 9.

Unfortunately for the facility of chronology, however, neither this nor any other standard measure of time based upon the succession of seasons, consists of an exact round number of days without a fraction; nor has the fractional part remaining over a whole number of days the advantage of amounting by any extent of repetition to a day, or even to any whole number of days.

This circumstance, as will presently appear, has been productive of grave inconvenience in history and chronology.

74. In their first rough attempt at the establishment of the annual standard of time, the Egyptians gave the year 360 days, divided into twelve equal months of 30 days.

This is supposed to have been the origin of the division of the circle into 360 degrees, and indeed of the prevalence of a duodecimal modulus in many other popular measures.

The subsequent addition of the five complementary days is attributed to an Egyptian god or hero called by the Greeks HERMES, with the distinguishing appellation of TRISMEGISTOS, *thrice-greatest.*

75. This interval of 365 days was as near an approximation to the period of the seasons as could be made in round numbers. Nevertheless its continuance would, after the lapse of a certain time, have been the cause of inextricable confusion. Let us see whether we cannot make this apparent.

The true period marked by the return of the seasons is now known to differ from 365¼ days by a little more than eleven minutes. This difference, minute as it is, has been the cause of great difficulties in history and chronology. Let us, however, for the present put it out of view, and take the year as being 365¼ days exactly.

After the lapse of one year of 365 days the seasons would, therefore, return a quarter of a day later than in the preceding year. After another year of 365, they would return half a day later; after another, three-quarters of a day later; and after four years they would be an entire day later. Thus if spring began in the first year on the 21st March, it would begin in the fourth year on the 22nd March. In like manner it would begin in the eighth year on the 23rd, in the twelfth, on the 24th, and so on; being one day later every fourth year. In 30 times four years it would be a month later; and in 182½ times four years—that is in 730 years—it would be just six months later, so that Spring would commence on the 21st September, and Autumn on the 21st March. The first day of Summer would be 21st December, and the first day of Winter would be 21st June.

Such would be the ultimate effects ensuing from the adoption of a year of 365 days.

The confusion, historical and chronological, which would ensue from such a method of recording time must be obvious. If we found any event recorded in remote times which might have been affected by the season of the year at which it occurred, its date would supply no immediate indication of that. For anything indicated by the month in which it took place, it might have been in any season whatever, Spring, Summer, Autumn, or Winter. It is true, however, that the season might be discovered from the date, by calculating backwards, and allowing a day for every four years.

It is clear that after a period of four times 365 years—that is 1460 years—the seasons would return to the same days, having in the interval commenced upon every day of the year from the first to the last.

76. This discordance between the year of 365 days and the period of the seasons caused the former to be called the *Vague year;* the period of 1460 years, after which the seasons would return to the same days, was called the SOTHIC PERIOD, from some supposed relation to the *dog-star*, called SOTHIS.

77. However obvious were the objections attendant on the adoption of the year of 365 days it was not without defenders and partisans. The advantage claimed for it will, in our times, appear curious. It was said that such a year would cause all the festivals to fall successively upon every day in it, and would thus sanctify the entire year; just as if a Christian would at present advocate it on the ground that Christmas would in the course of fourteen or fifteen centuries fall upon every day in each season, of spring, summer, autumn and winter!

78. The Greeks, as we have seen, first measured time by months consisting alternately of 29 and 30 days, giving an average of 29½ days, a very close approximation to the true mean length of a lunation, and their year consisted of twelve such months. Such a year, however, consisting of only 354 days, deviated from the

periodic return of the seasons by more than eleven days, and after the lapse of no more than three years the seasons were put back more than a month; and after a period of eighteen years they were actually reversed, midsummer taking the place of midwinter, and *vice versâ*. The return of the seasons constituted so obvious and so natural a measure of the year, and was so intimately connected with the prosecution of human affairs, and especially with agriculture, that no measure of the year which varied so much from it could be long maintained; and, as we have already stated, attempts were soon made in all the provinces of Greece to bring the series of twelve months into accordance with the period of the seasons, by adjusting their several lengths so as to make a total of 365 days: an interval so near the true succession of the seasons that an age must elapse before any important discordance would have been rendered manifest.

Religious questions, however, intervened and raised serious difficulties among the Athenians. The festivals and ceremonies connected with the worship of the gods all originated at an early epoch when the lunar phenomena alone formed the basis of their chronology. Certain observances were required to be made in certain phases of the moon, and when those phases, by the changes in the lengths of the months, no longer recurred upon the same days of the year, but assumed a character similar to that of the moveable feasts of the Christian church, it became necessary in order to fix beforehand the times of their celebration, to calculate the days of the lunar phases, and, in a word, to create a calendar.

The difficulties which thus arose in the imperfect state of astronomical science at that epoch were seriously aggravated by a command proceeding from an oracle, to the effect that certain festivals appointed to be celebrated under particular lunar phases should be also held at certain seasons of the year. This at once rendered necessary the solution of the problem to bring into numerical accordance the series of lunations and the succession of the seasons, a problem which was at the time as far removed beyond the skill of the astronomers as that of the priests.

79. At length, about 432 B.C., Meton, an ancient astronomer, succeeded in obtaining a solution of it which, if not absolutely complete, was regarded as so satisfactory as to excite an outburst of popular enthusiasm. He stated that 235 lunations were exactly or so nearly equal to nineteen years that at the end of that period the full moons would again fall upon the same days of the year, and that, consequently, if the series of full moons were recorded for any single period of nineteen years, indicating the days upon which they severally took place in each year, they must recur upon the same days in every succeeding period of nineteen years,

and must have in like manner occurred upon the same days in every past period of nineteen years. Thus all calculation of the recurrence of the lunar phases was rendered unnecessary. The lunar calendar of any interval of nineteen years was merely a reproduction of the lunar calendar of the preceding interval.

This period of nineteen years was, and is still, called the METONIC CYCLE.

80. This discovery which was made public by Meton on the occasion of the celebration of the Olympic games in 432 B.C., excited such unbounded enthusiasm and admiration, and the benefits it conferred upon chronology were so highly appreciated, that the numbers expressing the dates of the full moons in a cycle were ordered to be inscribed in letters of gold upon the public monuments, and upon tablets in the temples of the gods. It is to this circumstance that is ascribed the fact that these numbers were afterwards usually written in the almanacks in gilt characters, and later when printing had been invented, they were distinguished by being printed in red ink, and they thus acquired the name of golden numbers, by which they are distinguished in the calendars of the present day.

81. Neither the brilliancy of this discovery, nor the glory of the Olympic crown, nor the great popularity with which he was surrounded, protected Meton from the shafts of his illustrious contemporary Aristophanes, who attempted to turn him into ridicule and bring him into discredit by introducing him among a group of charlatans in the well-known comedy entitled "The Birds" (*Ορνιθες*).

82. It is a curious fact that the accordance of the succession of the lunar phases with the Metonic cycle has become more and more precise, as the motions of the sun and moon in the heavens have been more exactly ascertained. The mean length of a lunation, which was already known in Meton's time with great precision, is 29·530589 days, and consequently 235 lunations consist of

$$29{\cdot}530589 \times 235^{d} = 6939^{d}\ 16^{h}\ 31^{m}\ 19^{s}.$$

The mean length of the year, which was not so well ascertained in Meton's time, is now known to be 365·24224 days, or

$$365^{d}\ 5^{h}\ 48^{m}\ 49{\cdot}5^{s},$$

and consequently nineteen such years consist of

$$(365^{d}\ 5^{h}\ 48^{m}\ 49{\cdot}5^{s}) \times 19 = 6939^{d}\ 14^{h}\ 27^{m}\ 41^{s},$$

from which it appears that 235 lunations exceed nineteen years by $2^{h}\ 3^{m}\ 38^{s}$.

After each interval of 19 solar years, therefore, the successive lunations would commence $2^{h}\ 3^{m}\ 38^{s}$ later.

83. It has been already stated that the Roman year consisting

first of 304 days, was immediately increased to 355 days; and that ultimately, by the complementary month called Mercedonius, 45 days were added to every fourth year. Thus each series of four years consisted of

	DAYS.
I.	355
II.	355
III.	355
IV.	400
	1465

So that the four years consisted of 1465 days.

The true length of four solar years being, however, only 1461 days, four Roman years as thus established would be four days too long; so that every four years the seasons would fall four days earlier in the year, and in the short period of thirty years, they would be severally moved back a month.

84. This consequence being soon rendered apparent, a remedy for it became necessary, and that which was first adopted was one of the worst expedients that could have been imagined. A discretionary power was given to the pontiffs to intercalate as many days as they might consider necessary to bring the year into accordance with the succession of seasons.

As might have been foreseen, this measure speedily gave rise to the most gross system of abuses. Accounts being made up, payments made, and interest computed for all affairs private and public to the first days of the months, the pontiffs prostituted the powers conferred upon them to the most corrupt purposes. The temporary magistracy of those whom they favoured was prolonged, and that of those whom they opposed was abridged; payments to be made by their friends were postponed, those due by their opponents accelerated; the profits of the farmers of the revenue were augmented or diminished at their good will and pleasure, by the adroit management of the arbitrary intercalary days by which they were enabled to prolong or to abridge any months of the years. The disorders thus produced attained at length to such a pitch, that the festivals of autumn were celebrated in spring and *vice versâ.*

VII.—THE JULIAN REFORM.

85. It was reserved for Julius Cæsar not only to put an end to this confusion and the abuses in which it originated, but to establish a system of recording time, which has come down to our own epoch, and is denominated from its founder the JULIAN CALENDAR. He was aided in this great reformation by Sosigenes, an eminent

Egyptian astronomer of that day. He was, according to the laws, authorised to accomplish this, being himself chief pontiff.

Astronomical science had so far advanced, that the length of the period determined by the succession of the seasons was known to be about 365¼ days. But the adoption of a civil year conforming to this would have involved consequences of a highly impracticable kind. Thus, if we suppose such a year to commence at midnight, between the 31st December and 1st January, the succeeding year would commence at six A.M. on the next 1st January; the next at noon, on the following 1st January; the next at six P.M., on the 1st January of the third year; and, in fine, the next at the midnight between the 1st and 2nd January on the fourth year. Thus, in a series of four years, the first day of January would be transferred piecemeal, quarter by quarter, backwards to the preceding year.

This was evidently an impracticable measure. Julius Cæsar, who in the eminently practical character of his genius closely resembled Napoleon, resolved upon surmounting the difficulty by an expedient as simple in its execution as it was happy in its conception.

86. It was decided to adhere to years consisting of a whole number of days, and to allow the fractions to accumulate from year to year, until they should make up an entire day, and then to add that as a supplemental day to the year in which the accumulation should arrive at its limit. Since therefore the fraction over the round number of 365 days was assumed to be a quarter of a day, it would at every fourth year amount to a day. It was, therefore, decided to accomplish the object by giving one additional day to such fourth year. These four successive years were to be thus composed:—

	D.
I.	365
II.	365
III.	365
IV.	366
	1461
Mean length	365¼

The object was, therefore, attained without annexing fractional parts of a day to the year.

The additional day given to the fourth year was introduced into the month of February, making that month 30 instead of 29 days.

COMMON THINGS.

TIME.

CHAPTER IV.

87. Year of confusion. — 88. New arrangement of the months. — 89. Mistake of the Pontiffs.—90. Leap-years.—91. Historical dates.—92. Day of the equinox.—93. What is the equinox ?—94. The two equinoctial points.—95. Sidereal year.—96. Precession of the equinoxes.—97. Equinoctial year.—98. Civil year.—99. Difference between it and the Julian year.—100. Effect of this difference.—101. Cause of the reformation of the Calendar.—102. Discordance between the real and ecclesiastical equinox.—103. Gregorian reform.—104. Gregorian Calendar.—105. Its compensating effect.—106. Resistance to its adoption.—107. Dates of its adoption in different countries.—108. In England.—109. Its reception there.—110. Occasional agreement of the new and old styles.—111. Anecdotes relating to the change.—112. Russia adheres to the old style.—113. Commencement of the year.—114. Various in different countries.—115. In England.—116. Old and new style in England.—117. Temporary inconvenience attending it.

It will be remembered that the Romans counted the days of the month backwards, and that those of the latter part were reckoned from the calends or first day of the next month. Now it happened that the sixth day of February, counting backwards from 1st March, called the sexto-calendas was consecrated to a festival celebrating the expulsion of the Tarquins. It was resolved to place the supplementary day of the fourth year immediately before this sexto-calendas, and to avoid changing the denomination of the other days it was decided to call it a second sexto-calendas. It was therefore denominated BISSEXTO-CALENDAS, and the year in which this additional day was intercalated was and still is called A BISSEXTILE YEAR.

The commencement of the year was ordered to take place on the day of the new moon, which occurred next after the winter solstice of the preceding year. This day was accordingly called the 1st January, 709, from the foundation of Rome, and as the commencement of our era was the year 754 from the foundation of Rome, it follows that the date of the Julian reform was 45 B.C. and consequently the year preceding the murder of Cæsar.

87. This admirable arrangement provided for the future, but it did not repair the consequence of the past abuse and disorder. The complementary month called Mercedonius had been the subject of constant maltreatment by the pontiffs, having been abridged and extended in the most capricious and arbitrary manner, so as completely to derange the position of the seasons, relatively to the commencement and the close of the year. To rectify this some bold and exceptional temporary measures were indispensable. Cæsar being chief pontiff exercised the power which his predecessors in that office had so grossly abused to rectify these disorders, and restored by a violent and exceptional measure the day of the spring equinox to the 25th March, the date which it held in the time of Numa. To accomplish this, he decreed that the year 708 from the founding of Rome should consist exceptionally of 445 days. These 445 days were composed in the following manner:—

		Days.
The common year		355
Month Mercedonius		23
Two extraordinary months between November and December:	First	33
	Second	34
		445

The year in which these changes were introduced came to be called the "YEAR OF CONFUSION." This year was 46 B.C.

88. Besides thus re-adjusting the place of the equinoxes, the

distribution of the 365 days among the twelve months was rearranged. It was ordered that the odd months, counting from the beginning of the year should contain 31 days each, and that the others should contain 30, except February, which in common years was to contain 29, and in bissextile years 30 days.

This natural and easily remembered distribution was disarranged soon after to gratify the frivolous vanity of Augustus. It has been already stated that the month Sextilis had its name changed to Augustus in compliment to that emperor. Not satisfied with thus having his name perpetuated, he insisted that the number of days in his month should not be less than in Cæsar's. The day added to August was therefore taken from February, which was thus reduced to 28 days for common, and 29 for bissextile years. The months definitively stood as follows:—

	Days.		Days.
January	31	July	31
February	28 or 29	August	31
March	31	September	30
April	30	October	31
May	31	November	30
June	30	December	31

The alternation of 30 and 31 days proposed by Cæsar is therefore preserved with the exception of July and August, two months of 31 days in immediate succession.

It was attempted at later periods of the empire to prostitute the calendar by changing the names of the latter months of the year into those of Tiberius, Claudius, Nero, and Domitian; but the good sense of the Roman public resisted such an ignominy.

89. The death of Cæsar in the year after this reform had been decreed, threw the task of its realisation into the hands of the pontiffs, whose very first act betrayed a total misapprehension of the meaning of the most important of the conditions of the new system. The terms of the Julian edict, by which the recurrence of the bissextile year was defined, have not come down to our times; but it is certain that the pontiffs interpreted the periodic addition of the intercalary day as designed for every third year, and not every fourth year. That they were not set right by any contemporary authority like Sosigenes, who, knowing the object to be accomplished by the expedient, might have demonstrated the sense of the edict, if the words in which it was expressed were equivocal, only shows in a striking point of view how rare this sort of knowledge must have been in that age. However, it is certain that for the first 36 years after the reformation, every third, instead of every fourth year, was taken as a bissextile year, and consequently that these 36 years, including 12 instead of 9

intercalary days, had a total length greater by 3 days than was due to them by the Julian system rightly understood. When this error was at length perceived, the consequence of it was rectified by order of Augustus, who decreed that for three successive periods of four years, the intercalary day due to every fourth year should be omitted, so that the excess given to the preceding 36 years was compensated by an equal deficiency in the 12 following years, after which the regular recurrence of bissextile years was observed.

The mistake is known to have arisen thus—In Roman counting, every *fourth* is our *third*,

1 2 3 4 1 2
A B C D E F G H I J K &c.
1 2 3 4 1 2 3 4

Livy describes the cycle of 19 years as *one which* begins every *twentieth* year.

90. The common name given to bissextile years in our language is LEAP YEARS, which the dictionaries explain by stating that "every fourth year leaps over a day more than a common year." It is, however, objected by some that the term LEAP year is inappropriate, inasmuch as leaping over a day would imply its omission, instead of which in such years an extra day is thrust in.

The term is also explained by stating, that it implies that a day is leaped over in the calendar without giving it a distinct name.

It is worthy of remark that in the ecclesiastical calendar of foreign countries, the day called "intercalary" in bissextile or leap years, is not the 29th but the 24th of February.

91. It will be perceived from what has been stated, that some confusion prevailed for nearly forty years from the date of the Julian reform, that is until very near the commencement of the Christian era; nor is there any historical certainty as to the regular observance of the new method until the commencement of our era. It is certain, however, that the Roman years 761, 765, 769, &c., which were the years A.D. 8, 12, 16, &c., were counted as leap years, and about all succeeding dates there is no doubt.

From these dates, historians and chronologists have reckoned not only forwards but backwards, so as to reduce all historical events to the position in respect to the order of time which they would have held, if the Julian system had always existed. When we read of historical events, occurring in distant ages before these reforms in the methods of recording time, we are to understand that the dates assigned to them are by no means those which they bore at the time, and in the nation of their occurrence; but that by the labours of chronologists, the local dates given to them by the contemporary annalists, dates varying not only in different countries according to their different usages, but even in the same country in different ages, have been changed into those dates which they would have had if the Julian chronology had prevailed then.

It is evident that without this simplification and assimilation, historical dates would present a mass of confusion, which would be inextricable to all ordinary readers.

92. It has been already stated that the interval of 365¼ days, assumed in the Julian reformation as the length of a year, is not its true length, but differs from it by a very small fraction of a day. As we have now to explain the part which this very minute fraction has played in chronology, it will be necessary to convey to the reader a more clear and distinct notion of the meaning of the word *year*, than that which is included in the general statement that a year is the period after which the seasons are reproduced; for it may fairly be asked what determines the limits of the seasons? how are the exact moments of time at which they severally begin or end defined? For it must be observed that our enquiries now involving not whole numbers of days, but small fractions of a day, it is not enough to know that this or that season begins or ends on this or that day; we must know the hour, minute, second,—nay even the fraction of a second, which marks the epoch we desire to determine.

It is customary then to define the course of the seasons by the moment at which spring begins. It has been agreed to take for this the moment at which the centre of the sun's disc has such a position in the heavens, that if it were stationary there, day and night would be exactly equal, that the sun would be in short exactly twelve hours visible, and twelve hours invisible; twelve hours above, and twelve hours below the horizon.

It may be said that this definition is needlessly verbose and complex, inasmuch as it would be more simple and intelligible to say at once that spring begins *on the day of the equinox.*

Undoubtedly such a summary statement would be much shorter and more simple, and provided that it be clearly understood, and that it be sufficiently definite, it can be subject to no objection. But what is meant by the "day of the equinox?" We shall, of course, be answered that it is that day on which the sun is twelve hours above, and twelve hours below the horizon.

Very well! let us go to the almanac, and search for such a day. We take the almanac of 1854, and find that on 19th March the sun was twelve hours and one minute above, and eleven hours and fifty-nine minutes below the horizon. On the 20th it was twelve hours and six minutes above, and eleven hours and fifty-four minutes below the horizon, while on the 18th it was eleven hours and three minutes above, and twelve hours and fifty-seven minutes below the horizon. On no day of the month was it exactly twelve hours above, and twelve hours below the horizon; and the same result would be found by examining in the same manner the almanacs for other years.

It appears then that rigorously equal day and night is a phenomenon that never exists. It is no answer to this to say that the day and night in the instance produced and others differ only by a minute or two, because the question here involves only the consideration of those very minute intervals.

Since then the "day of the equinox" cannot mean a day on which day and night are equal, what is its exact meaning? We reply that it means very obviously the *day on which the equinox takes place*. But then what is in that case meant by the word equinox? We reply by turning back upon the explanation already given, that the equinox is that precise moment when the centre of the sun's disc has such a position that, supposing it to retain that position unchanged, it would be twelve hours above, and twelve hours below the horizon, during a revolution of the heavens.

93. But since the sun's disc has a continual easterly motion upon the heavens, moving at the rate of nearly 1° per day, or 2½′ per hour, it does not retain the position in question more than an instant. It moves round the heavens as the hand of a clock moves round its dial, passing incessantly from point to point. The exact point at which the centre of the sun is at the moment above described, is therefore called the equinoctial point, as the moment of time at which it passes through that point is called the equinox.

94. There are two equinoxes and two equinoctial points. The first takes place about the 21st March, and the other about the 23rd September.*

The former is called the vernal equinox, and the latter the autumnal equinox, because it has been agreed to fix the beginning of spring at the one epoch, and the beginning of autumn at the other.

The two equinoctial points are situate at opposite sides of the heavens, separated one from the other by an entire hemisphere, as must be evident when it is considered that the sun takes six months to move from the one point to the other.

95. Having thus conveyed a distinct notion of the meaning of the equinoxes, and of the equinoctial points, we shall find less

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* In the tables of sunrise and sunset given in the almanac, the effects of refraction are taken into account. These are omitted, however, in fixing the position of the equinoxes.

difficulty in explaining the different senses in which the word YEAR is used.

If the equinoctial points maintained a fixed position on the heavens, the interval between the moments at which the centre of the sun's disc would pass twice successively through either of them, would be in fact the interval during which the sun makes or appears to make a complete revolution of the heavens.

This interval is called the SIDEREAL YEAR.

Astronomers have ascertained the exact length of this year to be $365^d\ 6^h\ 9^m\ 10{\cdot}38^s$.

It appears, therefore, that this long interval has been ascertained to within the hundredth part of a second of its true value.

96. But the equinoctial points have not a fixed position on the heavens. They are on the contrary, subject to a slow displacement from year to year in a direction contrary to the motion of the sun. The amount of this annual displacement is small, being a little less than one minute of a degree,—that is, about the thirtieth part of the breadth of the sun's disc.

Small as this displacement is, it has been very precisely measured; and its effects, which are of the highest importance, as well in chronology as in astronomy, have been exactly appreciated.

On account of this removal of the equinoctial point backward, the sun arrives at it after making a revolution of the heavens, sooner than it would have done if it had not been displaced. This must be evident when it is considered that the equinoctial point, displaced in a direction contrary to that of the sun's motion, advances to meet the sun on its return. The sun therefore arrives at it before it makes a complete revolution of the heavens, and the time of each successive equinox *precedes* the time at which it would have taken place if the equinoctial point had been stationary.

This phenomenon has for that reason been called the PRECESSION OF THE EQUINOXES.

97. The effect therefore obviously is, that the interval between two successive equinoxes is less than the sidereal year.

This interval between two successive equinoxes is called the EQUINOCTIAL OR TROPICAL YEAR.

The sidereal year is of invariable length, and would on that account be well suited to be a standard measure of time. But it has one capital defect, which renders it totally unfit for civil purposes. It is not in accordance with the periodic returns of the seasons by which all mankind measure the year.

If the equinoctial points were stationary, the sidereal year would also be the equinoctial year, and in that case it would be coincident with the return of the seasons. But in consequence of the displacement of the equinoctial points, the commencement of the equinoctial anticipates that of the sidereal year; the extent of this anticipation, though very small at first, accumulating for long series of years, causes the seasons to take place successively at all imaginable parts of the sidereal year.

For these reasons the sidereal year has never been adopted as the civil year.

If the annual displacement of the equinoctial point were regular and constant, the precession of the equinoxes would be also constant; and the equinoctial year, differing from the sidereal year by an invariable quantity, would itself be invariable, and as it is in accordance with the succession of the seasons, it would be in all respects eligible as a standard measure of civil time.

But it so happens that this displacement is rendered variable by the operation of several causes. Its variations, however, are circumscribed within narrow limits. It alternately increases and decreases, and has a certain ascertainable average amount. On account of this variation, the equinoctial year is of slightly variable length, and is therefore not fit for a standard measure of time.

98. This being the case, and the mean annual displacement of the equinoctial point being accurately ascertained, a fictitious equinoctial point is supposed to exist, which has this mean annual displacement, and the interval between two successive returns of the sun to this fictitious equinoctial point being invariable, is adopted as the standard, and is called the MEAN SOLAR OR CIVIL YEAR.

Although rigorously this year does not therefore correspond with the returns of the seasons, it never varies from them by any interval great enough to be perceived or appreciated by any but astronomers.

The exact length of the mean solar or civil year is

$$365^{d}\ 5^{h}\ 48^{m}\ 49^{s}{\cdot}54,$$

being less than the sidereal year by $20^{m}\ 20^{s}{\cdot}8$.

99. Such being then the actual length of such a year as would always remain in accordance with the successive returns of the seasons, let us see to what extent the year of the Julian calendar differs from it, and how such difference would affect chronology.

The Julian year being 365¼ days, the difference between it and the mean solar year is easily found.

	D.	H.	M.	S.
Julian year	365	6	0	0·00
Mean solar year . . .	365	5	48	49·54
Difference			11	10·46

100. It appears, therefore, that the Julian years would depart from the course of the seasons at the rate of $11^{m}\ 10^{s}{\cdot}46$, or about

the 129th part of a day per annum. The departure accumulating from year to year would amount to a whole day in 129 years, to two whole days in 258 years, to three in 387 years, and so on.

Now, although such a departure would not be perceptible during the lives of a single generation, it must evidently become so after some centuries. The equinox falling back towards the beginning of the year at the rate of one day in 129 years, was in the fifteenth century thus thrown back as much as eleven days.

It is evident that the continuance of this from century to century would have thrown the equinox back from day to day until it, and consequently the seasons, would have successively assumed every possible position in the year.

VIII.—THE GREGORIAN REFORM.

101. Although in a more civilised and enlightened age this would have been a reason sufficiently urgent to undertake a revision and correction of the calendar, we are indebted for the reform which took place to other and different causes.

102. It was the rule of the Church to celebrate the festival of the Resurrection at a time not far removed from the 21st March, which was taken to be the day of the equinox, depending however also upon conditions connected with the lunar phenomena with which we are not at present concerned, but which we shall explain fully on another occasion. If therefore the real equinox were subject, as we have stated, to a gradual change, which would throw it back from year to year, so that it would fall each successive year earlier and earlier, while the festival of Easter, still related to the 21st March, would necessarily be farther and farther removed from the equinox, it must obviously happen in the course of time that the festival would fall successively in every season of the year, and indeed on every day of the year.

The Roman ecclesiastical authorities of the day becoming painfully aware of this, and sensible that no decree of pope or council could accelerate the motion of the equinox for the future, or carry it forward from the 11th to the 21st March; to repair the error of the past, resolved that since they could not bring the equinox to the 21st March, they would bring the 21st March to the equinox.

103. This change, with the others necessary to prevent the recurrence of a like discordance between the ecclesiastical year and the seasons, took place in the latter part of the sixteenth century, in the pontificate of Gregory XIII., from whom the reformed calendar came to be called the Gregorian calendar.

As at the epoch of the Julian reform, two errors were to be corrected, those of the past and those of the future. The accumulated effect of the past errors was that the real epoch of the spring equinox had fallen ten days behind the nominal day of its occurrence, which was the 21st March. The future cause of error was that an additional day every fourth year was too much, but that 129 years must elapse before the redundancy would cause the equinox to be one day behind its time.

104. To remedy the consequence of past errors, it was decreed that the days of the months should be all expressed by numbers, greater by 10 than those by which, according to the succession of time, they were expressed. Thus the 11th March, 1582 (the year in which the reform took place) was decreed to be the 21st March, and in like manner all the other days of the year were augmented by 10. By this expedient the last ten days of 1582 were thrown over into 1583, inasmuch as the 21st December, 1582, became 31st December, 1582, and consequently 22nd December, 1582, became 1st January, 1583.

The day of the vernal equinox thus recovered the date of 21st March. How it was secured in the undisturbed possession of that date, we shall now see.

By following the established rules of the Julian calendar, it would have been one day behind its date in 129 years from 1582, that is in 1711. To prevent this, it was decreed that the year 1700, which would by the Julian calendar be a leap year, should be a common year. One day being thus omitted, the equinox of 1711 would be restored to its date of 21st March. In like manner it would be again a day behind in 1840. This was in like manner to be prevented by making 1800 a common year, which ought to be a leap year. Again it would be a day behind its time in 1969, which would be set right as before by making 1900 a common instead of a leap year. Another period of 129 would go to 2098, which was remedied by making 2100 a common instead of a leap year.

Thus the equinox would be kept right by making three successive secular years 1700, 1800, and 1900 common years instead of leap years, leaving 2000 a leap year, but making 2100 a common year instead of a leap year, and going on from century to century in the same manner, leaving every fourth secular year a leap year, but making all the others common years. The series of secular years would therefore be as follows:—

1700 Common
1800 ,,
1900 ,,
2000 Leap
2100 Common
2200 ,,

2300 Common
2400 Leap
2500 Common
2600 ,,
2700 ,,
2800 Leap,

and so on. The secular leap years will always be those of which the first two figures are exactly divisible by 4 without a remainder, as 2000, 2400, 2800, 3200, 3600, &c., all the other secular years being common years.

105. Let us see whether the compensation thus produced for the errors of the Gregorian calendar is practically sufficient, for perfect it is not, nor is it possible for any such compensation to be so. It has been shown, that the Julian year was too long by the 129th part of a day very nearly. To compensate for this Pope Gregory XIII. does what? He takes away three days from 400 years, which is equivalent to taking $\frac{3}{400}$th part of a day from one year, whereas the quantity required to be deducted is the 129th part of a day, which is greater than the $\frac{3}{400}$th part. The compensation of Pope Gregory is therefore short of the requisite quantity by the difference between the 129th and the $\frac{3}{400}$th part of a day, that is by the 3969th part of a day.

Thus it appears that by following the Gregorian calendar the equinox will not be so much as one day behind its time until an interval of 3969 years elapses, counting from the year 1582, that is until the year of our Lord 5551. When that time arrives the evil may be staved off for another period of 3969 years, by declaring the year 5600 a common, instead of a leap year. We may, however, safely leave to the inhabitants of the earth at that epoch the management of the affair. Sufficient for the day is the evil thereof.

106. Notwithstanding the undeniable reasonableness of this reform of the calendar, and the manifest absurdity of persevering in calling the 21st March the vernal equinox, when all the world had the evidence of their senses to prove to them that the equinox had really taken place ten days earlier, the change proposed was not generally adopted. Protestant States were opposed to it because it emanated from Catholic ecclesiastical authorities, and as was wittily observed, they preferred rather to be in opposition to the sun than in accordance with the Pope. The nations professing Greek Catholicism were opposed to it because it emanated from the head of the branch of their Church which they denied to be orthodox.

The papal decree fixed the exact date of the commencement of the reform at the 5th October, 1582, according to the former style, which day was decreed to be called the 15th October.

107. In France the change was adopted on the 10th December, next following, which was called 20th December.

In the Catholic States of Germany it was adopted in 1584.

The Protestant German States, having resisted the reform for nearly twenty years, at length yielded, and accepted it in 1600, in which year the 19th February was declared to be 1st March.

Denmark, Sweden, and Switzerland, were later in the adoption of the change, but soon followed the example of Germany. Some Swiss towns nevertheless offered such vigorous opposition to the measure, that the intervention of the military was necessary to enforce it when adopted by the authorities.

In Poland, where it was adopted by the government as early as 1586, it encountered considerable opposition in certain towns, and even excited a serious insurrection at Riga.

108. The anti-papal spirit being much more dominant in England than common sense or scientific authority, the reform was resisted for nearly two centuries, so that the real had fallen above eleven days behind the legal date of the equinox. In 1752, however, the force of things at length prevailed over this discreditable bigotry, and the reform was introduced into the calendar, by declaring the 3rd to be the 14th September.

109. A measure of which the effect was to overturn the long established landmarks of time, and to substitute for them others, new and altogether strange to tradition and usage, could not be supposed to pass without exciting many reclamations among persons of all classes from the peer to the peasant. Personal feelings were excited at the unceremonious perturbation of birthdays and of marriage anniversaries. Religious exasperation was produced by the arbitrary transposition of the most solemn festivals. Even the moveable feasts already surrounded with some confusion, became for the moment confusion worse confounded. Political celebrations and the dates of historical events shared in the general disturbance.

In an essay on the ecclesiastical calendar, by Professor De Morgan, which was published in the Companion to the British Almanac, for 1845, some amusing examples of this are collected. A friend of the author, an eminent scientific man, not long since deceased, related of his own knowledge, when a boy, that a worthy couple in a country town, scandalised at the change of style in 1752, continued to attempt the observance of Good Friday on the old day. To this end they used to walk seriously, and in holiday costume, to the church door, at which the gentleman used to knock for a certain time with his cane, demanding admittance. On finding no admission, they walked as solemnly home again, and read the Church service appointed for the day. On the new and, as they regarded it, spurious Good Friday, they ostentatiously acted as if it either preceded or followed the genuine day, as the case might be, so as to render it manifest to their neighbours and friends, that they at least totally rejected the new style.

110. In the 48 years, between 1752, the date of the change of

style, and the end of the century, there were, however, 18 years in which harmony must have been re-established between the partisans of the new style and those who reverenced tradition, for in these years it chanced that the moveable feasts, according to both styles, fell upon the same days. "This," observes Professor De Morgan, "happens still occasionally, and will do so, though less and less frequently, until 2698 A.D., when it will happen for the last time."

Even still, after the lapse of more than a century, the Christmas Day of the old style is celebrated under the name of Twelfth Day, and the name of "Old Christmas Day" is still given to it in the calendar. It falls on the Feast of Epiphany.

111. Before the change of style, a popular belief prevailed in England, that at the moment of the midnight with which Christmas Day began, the cattle always fell on their knees in their stalls. Now when the change of style took place, it could scarcely have been expected that the arbitrary will of the legislature would be respected by these dumb animals, and it was accordingly found that they continued to perform the act of reverence, not on the Christmas Day of the law, but on that of the old style! The best of this joke was, however, that the Christmas Day of the law was a Popish institution, forced upon England by circumstances, and it was maintained that these Protestant cattle were all the more obstinate in their dumb protestation against the Romish innovation.

It appears, nevertheless, that in Catholic countries which acknowledged the authority of the See of Rome, in changing the style in 1582, inanimate things, not to say cattle, acknowledged the validity of the decree; for we have the high authority of the truly learned Riccioli, to whose astronomical works the scientific world is so largely indebted, to assure us that the blood of St. Januarius, which previously used to liquefy punctually on the 19th September, immediately changed the day of its miraculous liquefaction to the 19th September of the new style, which was the 9th September of the old style. Like the day of the nominal equinox, that of the miracle was accordingly put back ten days, in obedience to the papal bull.

Riccioli also mentions the case of a certain supernatural twig, which had been accustomed to put forth miraculous buds on Christmas Day. This Romish twig, unlike the Protestant cattle, as the astronomer assures us, was found to bud on the new Christmas Days which followed the publication of the Papal bull.

112. Of all Christian States, Russia alone still insists on adhering to the Julian calendar, and accordingly, by the further

accumulation of the effects of the erroneous length assigned to the year, the Russian legal equinoxes are now *twelve* days in advance of the real equinoxes.

113. The influence which long continued usage exercises upon the mind is such that we are always disposed to think, that what has been long established has been so by the nature of things, and therefore of necessity, and not at all by the arbitrary appointment of local and temporary authorities, or by the voluntary choice of the people. Thus, who does not imagine that it is for some natural and necessary reason that the year begins on the 1st of January? January is the first of the series of twelve months, and what can be more natural than to take its first day as the commencement of the year? But why is January the first month? It is marked by no peculiar or universally observable phenomenon. If the sun, on its first day, were seen to occupy any remarkable position, as, for example, that which it has at the equinox, or if the sun and moon were always found together on that day, or if a conspicuous eclipse, or any other striking phenomenon periodically presented itself on that day, a reason would be found why January is the first month, and why its first day is the first day of the year. But neither the month nor the day is signalised by such phenomena, nor by any which can be supposed to mark it by nature as the commencement of a chronometric period.

It might be imagined that at all events the first day of *some* month would be selected as the commencement of the year. No reason, as it would appear, could induce people to begin the year in the middle of a month, so that one part of that month should be in one year and the remainder in the other. Nevertheless, obvious as these considerations now appear, it is certain that they have had no weight with mankind. Other considerations of another order, exercising over the mind much more potent influences, have predominated, and years, accordingly, with different nations and in different ages, have had their commencement fixed upon days which have no reference either to astronomical phenomena, or the order or limits of the months.

114. Religious anniversaries, as might naturally have been expected, have played a prominent part in this chronological element. Christmas Day, Easter Day, and the Festival of the Annunciation, commonly called Lady Day, have been, in different countries and at different ages, selected as the first day of the year. Among the French, at the time of Charlemagne, the year commenced on Christmas Day. It commenced on Easter Day among the same people under the Capet monarchs, and this practice was very general in the twelfth and thirteenth centuries. In

England the year commenced on Lady Day (25th March) until 1752.

It must not be understood that this commencement of the year involved any change either in the months or in the order of their days. Thus when the year commenced on Christmas Day, that day was still called the 25th December, and was preceded by the 24th and followed by the 26th December; but the 24th December belonged to one year and the 25th to the next. In like manner, the two days which we now refer back to as the 24th and 25th March, 1751, were, at the time they actually occurred, called the 24th March, 1750, and 25th March, 1751. Thus 24 days of March belonged to 1750, and the remaining 6 days to 1751.

115. To us at present, with the habits of counting the years, months, and days to which we have been accustomed, such a method of commencing the years appears so absurd and attended with such strange confusion and disorder that we find it difficult to imagine how a people could ever continue the practice of it. Nevertheless it is certain, so far from any such impression existing at the time this usage prevailed, the announcement of the change of style, as it was called, which was decided upon by the legislature in 1751-2, encountered the most serious resistance, and excited popular disturbances of grave importance. The transfer of the beginning of 1752 from the 25th of March to the 1st of January, immediately preceding it, deprived the year 1751 of the months of January, February, and twenty-four days of March, nearly the whole of its three last months.

This change and the apparent sponging out from the course of time of eleven days exasperated the populace, who, assembled in the streets of London, and pursued the members of the government (among whom was the celebrated Lord Chesterfield) when they appeared, with cries and imprecations, demanding that their eleven days should be given back to them.

The traces of this custom in our country are still apparent in various practices. Leases are commenced and determined by Lady Day. The quarter days on which rents become due are regulated in the same manner. All rents are payable on Lady Day and Michaelmas Day, and not, as might naturally be expected, on the last days of June and December.

116. Until the adoption of the Gregorian calendar in England in 1752, the years, as has been already stated, commenced upon the 25th March, so that the year 1751 began on the 25th March, 1751, and ended upon the day now called the 24th March, 1752, while the year 1752 ended on the day now called the 24th March, 1753. Independently of the other obvious objections to such a system, it was out of all accordance with the mode of reckoning time prac-

tised by other nations of Europe, and great inconvenience and some confusion prevailed in the adjustment of dates in all international transactions. It was therefore resolved to include in the reformation of the calendar the change of the commencement of the year, from the 25th March to the 1st January, which was accomplished by declaring that the days, from the 1st January, 1751 (as formerly counted) should be taken as belonging to 1752, and that 1752 should end on the 31st December, and 1753 begin on the day formerly called the 1st January, 1752. Thus, in fact, the months of January, February, and twenty-four days of March, were transferred from each year to that which succeeded it.

This will explain the peculiar way of expressing dates which is found in all documents and printed works which appeared at, and for some time after the reform was adopted. Both dates, the new and the old, according to the reformed and unreformed style, were usually expressed, the old above and the new below a line, like the numerator and denominator of a fraction. Thus, for example, the day which was the 19th June, 1753, in the old style, being the 30th June, 1753, in the new style, the date was written thus, $\frac{19}{30}$ June, 1753. In other cases the month was changed as well as the day; thus the day which was the 30th June, 1753, old style, became the 11th July, new style, and the date was written

$$\frac{\text{30th June,}}{\text{11th July,}}\ \text{1753.}$$

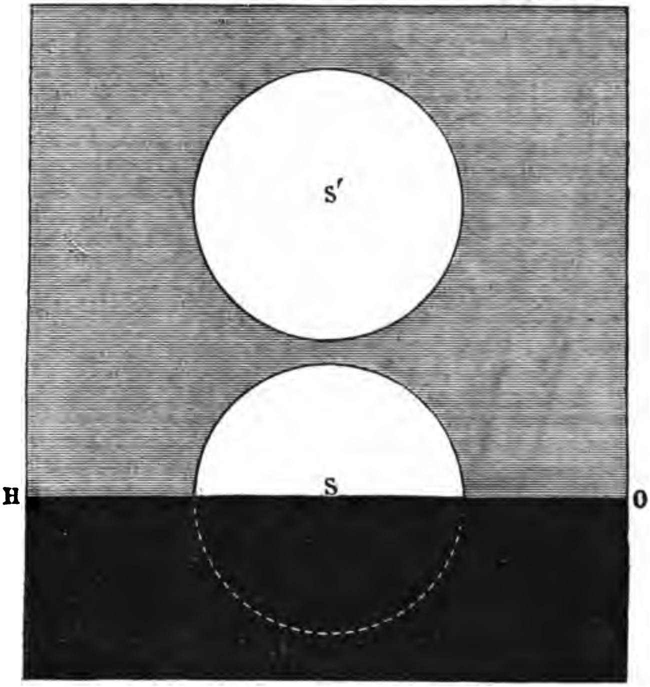
In other cases again, the day, month, and year were all changed, as, for example, the day which, in the old style, was the 23rd February, 1753, in the old style, became the 6th March, 1754, in the new style, and was thus written :—

$$\frac{\text{23rd February, 1753.}}{\text{6th March, 1754.}}$$

117. The difficulties which such a change at first produced among the great mass of the population of the country, who, from their limited education and information, must have been unaware of the many important grounds on which the reform was based, can be easily conceived.

Happily, however the reform was realised, and the inconveniences which first attended it disappeared after a few years, so that the English dates were not only brought into accordance with the course of the seasons, but with those adopted by other civilised nations.

Fig. 1.



COMMON THINGS.

THE ALMANACK.

CHAPTER I.

1. The Almanack.—2. The Calendar.—3. The contents of an Almanack —Predictions.—4. Its prophetic character abused.—5. Saints' Days.— 6. Date of the year.—7. Christian era.—8. Discrepancy between the reckoning of Astronomers and Chronologists.—9 When a century begins and ends.—10. Commencement and duration of the Seasons.— 11. Beginning of the year.—12. Fixed and moveable Feasts.— 13. Easter.—14. Not dependent on the phases of the Moon.— 15. By what rule determined.—16. Rule not generally understood.— 17. Equinox.—18. Ecclesiastical Moon.—19. Age of the Moon.— 20. Full Moon.—21. Error in the expression of the rule.—22. Lunar cycle.—23. Average length of civil and astronomical cycles agree.— 24. Fictitious moon never far distant from real moon.—25. Golden

Number.—26. Epact.—27. Used to determine the date of Easter.—28. Amount of separation of fictitious from real moon.—29. Limits of variation of date of Easter.—30. Earliest possible.—31. Latest possible.—32. Paschal Moon.

1. Of all books the Almanack is the most indispensable. So constant is the need for it, that, unlike other books, it is not deposited on the shelf, but lies ready at hand on the table. This general and constant utility, which ought to have exempted it from fiscal restriction, was precisely the circumstance which marked it out for the fatal visitation of the Stamp Office, and raised, thereby, for many years a barrier against its improvement. The moment of its emancipation from the Chancellor of the Exchequer having, however, at length arrived, it was indefinitely multiplied, assumed a thousand shapes, was offered at prices suiting all pockets, in dresses suiting all tastes, with accessories and appendages adapted to the exigencies of all avocations, and was sometimes even given gratuitously as a convenient vehicle for the commercial announcements which accompanied it.

One might imagine that a book thus so universally necessary would be as universally understood; nevertheless it may be fairly questioned whether one in ten thousand of those who daily consult it have any clear or definite notions of the import of even those parts of it to which they refer, and it is beyond all doubt that of many other parts they have no notion whatever. It has, therefore, appeared to us that some explanatory notice of its contents will not be unacceptable to our numerous readers.

Almanack, or Almanach, is an Arabic term derived from the word manah, *to reckon.*

2. In the almanack the Calendar holds a prominent place, so prominent indeed that the terms are sometimes used interchangeably. Nevertheless, *Calendar* has a more special and limited application. The first day of the Roman months was called calends, and hence a table showing the successive days of each month, and indicating the festivals and anniversaries civil or religious, which fell upon them, came to be called The Calendar.

It has been already explained in our Tract on "Time," that the word month has various senses. It may mean the moon's periodic time, that is, the time it takes to make a complete revolution round the earth. It also expresses the time which elapses between two successive new moons. This is called a Lunar month, and sometimes a Synodic month. In law, four weeks are taken to be a month. The year consists of twelve unequal parts, which are called Calendar months. These are the months which have received the names with which every one is familiar.

3. The almanack is a year-book, and is published before the commencement of the year whose date it bears, and to which its contents are related.

The contents of the almanack are, therefore, necessarily predictions.

The prediction of fixed anniversaries, whether civil, religious or natural, requires no calculation, since they fall from year to year upon the same days. The recurrence of many celestial phenomena, which are of great popular and civil interest, varies from year to year; and some religious and civil festivals and observances which are conventionally regulated by them, are subject to a like variation, and the prediction of the days of their recurrence depends on similar calculations.

4. The people of all classes in all countries seeing the precision with which so many and such various phenomena were foretold, were not slow to manifest a craving after like predictions of events of quite another order; and almanack makers were not—and are not even now—wanting who pander to this demand. We have, accordingly, almanacks including predictions of the vicissitudes of weather, of the occurrence of great political events, and in short of everything which can be imagined to gratify the spurious appetite of the credulous. It must be admitted, to the discredit of certain of our public bodies, that they have long condescended to traffic in this sort of charlatanism, and to derive a revenue from thus imposing on public credulity. If precedent, however, can be admitted as any extenuation of this practice, they may claim to have sinned in good company, for Arago relates that he had the following anecdote from Lagrange.

"The Berlin Academy, so celebrated for the vastness of physical discoveries and researches which were consigned to its transactions, formerly derived its chief revenue from the circulation of its almanack. This publication from an early period included a mass of pretended predictions of meteorological phenomena and political events, like those which figure in some of our own almanacks of much more recent date. Ashamed of sanctioning the publication of such absurdities, the Academy, upon the proposition of one of its leading members, resolved at one time upon suppressing them and supplying their place with more rational and useful matter.

"The immediate consequence of the reform was the almost total suspension of the revenues of the Academy by the great decrease of the sale of the almanack, so that the learned body was literally starved into compliance with the public demand, and compelled to reissue annually a collection of pretended predictions which were a subject of ridicule to those who invented and compiled them."

A similar circumstance occurred with respect to Moore's Almanack, of which the sale was reduced in amount by the omission of the column which assigned the effects produced by the signs of the zodiac on human members.

Another of the early almanacks which owed its immense circulation to the same cause, was one published at Liège, under the name of Matthew Laensberg, a canon of that city. "When we speculate on human credulity," observes Arago, speaking of this almanack, "we may be confident of success. It is in vain that, from year to year, the events are in flat contradiction to the predictions. The public does not the less resort to the famous almanack, so true is the saying of La Fontaine:—

L'homme est de glace aux vérités,
Il est de feu pour le mensonge."

Arago relates a curious accidental coincidence which gave the Laensberg Almanack prodigiously increased vogue. In the Almanack for 1774, there appeared a prediction that "one of the most favoured ladies would play her last part in the month of April." Now, it so happened, that in the month of April, Louis XV. was attacked at Versailles with the small-pox, and the notorious Madame Dubarry was expelled from the palace.*

5. The religious anniversaries indicated in the calendar, consisting principally of the days consecrated by the Church to the commemoration of saints and martyrs, necessarily vary in different Christian countries, according to the varying forms of the faith. The personages recognised as saints in the Roman Church are at least six times as numerous as the days of the year; and although the Greek Church does not recognise exactly the same collection, their list is equally abundant. A selection has been made by each branch of the Church, and the name of a saint or martyr is appropriated to each of the three hundred and sixty-five days; and to such an extreme is this carried, that a saint is even given to the intercalary day in bissextile years. Thus, in the Roman Church, the intercalary day is appropriated to St. Damien, and in the Greek branch to St. Cassian.

The identification of the days of the year severally with the names of canonised personages, will explain the familiar allusions to the "Saints of the Calendar."

In Protestant States, and more especially in England, this long list of saints is greatly curtailed, all those whose canonisation took place subsequently to the imputed corruption of the Church being rejected. In Catholic countries, however, the names registered in the calendar have become so closely interwoven with the national manners and customs, that it is unlikely that any reformation should efface them. It is the general practice to celebrate the anniversary of each individual, not, as with us, upon that of his or her birth, but upon the day consecrated to the memory of the saint whose name he or she bears. By this usage each day in the calendar becomes as it were the peculiar property of certain individuals, and to efface the saints would be practically to rob all the world of their festivals. In certain times and among certain people such a measure would excite an insurrection.

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* For a more recent specimen of the effect of such an accidental coincidence occurring among ourselves, see our Tract on "Weather Prognostics."

6. The very first date indicated in the Almanack, that from which it takes its title, and which is marked upon its back, the number designating the year, may require some brief explanation. What is meant, for example, by the year 1855? What is its beginning? what its end? From what point of departure are its units reckoned? 1855 since when? These are questions to which the answers are not quite so obvious as they may seem.

7. During the first five centuries after the birth of Christ, the Christians, comparatively few in number, and scattered among different and distant peoples, used in their records no other mode of expressing dates than those which prevailed among the nations of which they severally formed a part. In 532 A.D., when their numbers and importance had augmented, Dionysius Exiguus, a monk of Scythian birth, proposed that all Christians should adopt the epoch of the birth of Christ as their point of departure in counting time and in the expression of dates. This rendered necessary an investigation into the question of the date of that event. Dionysius made historical researches, the result of which assigned the birth of Christ to the 25th day of December, in the 753rd year from the foundation of Rome.

It might have been expected, therefore, that the first Christian year would commence on that day, and that its anniversary would be the first day of each succeeding year. It was, however, found inconvenient to change the commencement of the year, and it was resolved to adhere to that of the Roman year theretofore used by the Church—that is, to the 1st January, and that the first year of the Christian era should be the 754th year from the foundation of Rome. According to the mode of reckoning finally adopted, therefore, the year 1 A.D. was that which commenced at the moment of the midnight between the 31st December in the 753rd, and the 1st January in the 754th year of Rome.

The uncertainty which must necessarily attend the exact date of an event so remote as the birth of Christ, occurring moreover in an obscure corner of a remote Roman colony, and though attended with future consequences so important, invested with no circumstances which could lead to its having been recorded in the public annals, does not at all affect chronology; since whatever may have been the actual day of Christ's birth, that which connects the Christian with the ancient chronology is the first day of the year 754 of Rome.

To convert any year A.D. into the corresponding year of Rome, it is only necessary therefore to add 753 to it. Thus the year 1 A.D. was the year 754 of Rome, the year 20 A.D. was the year 773 of Rome, and so on.

It will be observed that the first year of the Christian era is not, as might be imagined, that of the birth of Christ, but the following year. It is the year in which, according to the researches of Dionysius Exiguus, Christ completed his first year.

8. Since, according to the Christian chronology, time is counted thus prospectively forward from the birth of Christ, the *year after* that event being taken as the first year of the series, it might by analogy be presumed that in counting time retrospectively the *year before* the same event would be taken as the first year of the backward series. Thus while the year after that of the birth of Christ is 1 A.D., the year before that of the birth of Christ would be the year 1 B.C., and consequently that the year itself in which Christ was born would be either 0 A.D. or 0 B.C. indifferently. By such a mode of expressing dates, the interval between any day in any year A.D., and the corresponding day in another year B.C., would be found by adding together the numbers expressing the years. Thus the interval between 1st July, 1 A.D., and 1st July, 0 B.C., was 1 year; the interval between 1st July, 1 A.D., and 1st July, 1 B.C., was 2 years; the interval between 1st July, 15 A.D. and 1st July, 14 B.C. was 29 years, and so on.

And this is, accordingly, the method of expressing dates which astronomers use. It is, however, unfortunately, not that adopted by historians and chronologists. According to these the year 753 of Rome, in which Christ is supposed to have been born, is the year 1 B.C., and consequently all their dates B.C. exceed the corresponding dates of astronomers by 1. Thus the year which astronomers call 500 B.C., historians call 501 B.C.

To find, therefore, the interval between any day in a year A.D. and the corresponding day in any year B.C. when the historical dates are used, it will be necessary to add together the two dates and subtract 1 from their sum.

9. Historical events are often referred to by stating that they occurred in such or such a century. Now one might well suppose that there could arise no obscurity or confusion in the use of such a term, yet it is notorious that after the year 1800, questions were

constantly raised in society as to whether such or such a day or month belonged to the eighteenth century or to the nineteenth.

The first day and the starting point or zero of the Christian chronological scale was the midnight with which the 1st January, 1 A.D. commenced. This was the moment, therefore, at which the *first century* began, and it ended evidently when, dating from that moment, 100 complete years had elapsed. The first century, therefore, terminated and the second began at the midnight between the 31st December, 100 A.D. and the 1st January, 101 A.D. In like manner the second century terminated and the third began at the midnight between the 31st December, 200 A.D., and the 1st January, 201 A.D. It is evident, therefore, that the entire year 100 A.D. belonged to the first century, and the entire year 200 A.D. to the second century; and, in the same manner, it follows that the entire year 1800 A.D. belonged to the eighteenth century. The eighteenth century therefore commmenced with the 1st January, 1701 A.D., and terminated with the 31st December, 1800 A.D., both these days belonging to that century. In like manner the first day of the nineteenth century was 1st Jan., 1801 A.D., and its last day will be 31st December, 1900 A.D.

10. One of the series of dates predicted in the almanack are those which mark the commencement of the seasons. The winter terminates and the spring commences at the moment of the vernal equinox; the spring terminates and the summer commences at the moment of the summer solstice; the summer terminates and the autumn commences at the moment of the autumnal equinox, and the autumn terminates and the winter commences at the moment of the winter solstice. The conditions which determine the equinoxes and solstices have been explained in our Tract on "Time."

Owing to a certain small variation in the rate at which the sun moves annually round the firmament—the cause of which has been explained in the same Tract—the seasons are not equal in length. The following are their lengths respectively:—

	D.	H.	M.
Spring	92	20	50
Summer	93	14	7
Autumn	89	17	49
Winter	89	1	2
	365	5	48

If the civil year, that is the year of the almanack, were identical with the equinoctial year, the seasons would commence respectively always upon the same days of the year. But although the civil year in the long run does not vary to any perceptible extent from the equinoctial year, this coincidence is not continual and results from the compensation produced by the device of bissextile or leap years, for a full explanation of the origin and purpose of which, see our Tract on "Time." By this expedient the civil years form a quadrennial cycle, consisting of three years of 365 days, and one year of 366 days. Now it will be easy to see that the consequence of this is, that the commencement of spring oscillates forward and backward alternately, being for the first three years of the cycle continually $5^h\ 48^m$ later, and in the last year $18^h\ 12^m$ earlier. On this account the first day of spring sometimes falls upon the 20th and sometimes on the 21st March.

As the length of the seasons respectively remains the same, it follows that the commencement of them severally is subject to a like variation. The commencement of summer oscillates between the 21st and 22nd June, that of autumn between the 22nd and 23rd September, and that of winter between the 21st and 22nd December.

To make this more evident let us take for example the quadrennial cycle, which commenced with the year 1853. The commencement of spring in the year 1853 was at $4^h\ 40^m$ in the afternoon of the 20th March. The year 1853, having only 365 days, while the interval between the two successive equinoxes is $365^d\ 5^h\ 48^m$, it follows that the commencement of spring in 1854 was $5^h\ 48^m$ later, and consequently took place on the 20th March, at $10^h\ 28^m$ in the evening. In the same manner, 1855 having only 365 days, the next commencement of spring is again $5^h\ 48^m$ later, and consequently takes place at 16 minutes past 4 o'clock in the morning of the 21st March. The following year, 1856, is, however, leap year, and has 366 days, while the interval between the equinoxes being only $365^d\ 5^h\ 48^m$, is $18^h\ 12^m$ less, and consequently the commencement of spring will be $18^h\ 12^m$ earlier in 1856 than it was in 1855, and, therefore, will take place at 4 minutes past 10 o'clock in the morning of the 20th March.

Thus the commencement of spring alternately advances and retrogrades; but the Julian cycle of four years, modified by the Gregorian cycle of 400 years, produces such a compensation, that for many thousands of years it cannot be earlier than the 20th or later than the 21st March, and the variation of the commencement of the other seasons is subject to similar limits.*

11. It will be evident, therefore, that although the year, in respect to its length, has a relation to the course of the seasons, it has no such relation in respect to its beginning and end. It

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* See Tract on "Time."

might have been supposed that, as all civilised people have concurred in adopting the course of the seasons as the great unit of time, they would have also fixed the limits of these units as they succeed each other, by making them correspond with the natural limits of the seasons. It is a very remarkable fact, nevertheless, that, although various beginnings and endings of the year have been adopted at different ages and in different nations, not one that we know of was determined by the natural limits of the seasons.

12. Some religious observances, such, for example, as Christmas, the Assumption, the Annunciation, always return upon the same days of the same month. Others, such, for example, as Easter, Trinity Sunday, Whitsunday, Corpus Christi, return on different days in each successive year, and are hence called MOVEABLE FEASTS.

To assign from year to year the dates of these moveable feasts is one of the chief religious uses of the calendar.

The principal of the moveable feasts, and that upon which the dates of all the others depend, is Easter,* or the festival of the Resurrection.

13. The Resurrection took place at or near the full of the moon which followed the equinox. This was also the time when the Jews were accustomed to celebrate their festival of the Passover. The celebration of that feast was regulated not only by the sun, but also by the moon, and as the period of the lunar phases is not commensurable with that of the seasons, the Passover was necessarily a moveable feast, in reference to an equinoctial year. The Christian festival was celebrated at the Paschal full moon, because its origin was connected with the *time* of the Passover. Many of the early Christians held Easter to be the Jewish Passover continued as a Christian rite, and celebrated it on the day of the Passover instead of the Sunday after. The Nicene Council put a stop to this notion and practice; and means were taken at the reformation of the calendar to prevent the Christian festival from falling actually upon the same day as that of the Jewish Passover.

14. It is a great error, though a very common one, to suppose that

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* The Saxons had a goddess to whom they sacrificed in the month of April, called *Eoster* (known in Greek as *Astarte*, and in the Hebrew as *Ashtoreth*). To this goddess, according to Bede, they sacrificed in April, which they called *Eoster-monath*. Some have thought that the word *East* in Saxon referred to rising, and that the point of the compass thus gets its name from the rising of the sun, and the festival from the rising of the Saviour. But the former is the most probable derivation. Christian rites and usages sometimes acquired the names of their heathen predecessors.

the date of the festival of Easter has a strict dependence upon the periodical phases of the moon. As our knowledge of astronomy has been for ages progressive, and as the tables of the lunar motions more especially have been subject to continual improvement, being rendered more and more exactly in accordance with the phenomena as science has advanced, it would follow that, if Easter were strictly regulated by the moon, the ecclesiastical authorities, from whom the calendar has always emanated, would be dependent on the astronomers of the time being for the means of predicting from year to year the days to be appointed for the celebration of Easter; inasmuch as a rule prescribed by the astronomers of the 14th century would fail before the improved knowledge of those of the 15th; as the rule prescribed by the latter would be rendered erroneous by the still more exact knowledge obtained by those of the 16th, 17th, 18th, and 19th.

Now, any person who will refer to the prefatory matter prefixed to the Book of Common Prayer, will see that the means of predicting the days upon which the Feast of the Resurrection will fall for centuries to come, are given entirely irrespective of the contingent discoveries of astronomers, and of the possible errors which might have prevailed in times past as to the lunar motions.

That approximate coincidence between the epoch of the celebration of the Resurrection and the astronomical dates of the vernal equinox and the full moon was designed, is undoubtedly true, and that the technical rules laid down for calculating from year to year the day of the celebration of the Resurrection, does lead to a certain rough correspondence with the lunar phases, may be admitted. But the determination of Easter-day has no necessary dependence on, and is not meant to be defined by, the actual lunar phenomena as seen in the heavens.

15. According to the rule established by the Roman branch of the Catholic Church, and which has been followed by the Church of England, the day of the celebration of the Feast of the Resurrection is determined, according to the explanation of the English Church, in the following manner:—

Find the day of the first full moon which occurs on or after the day of the spring equinox. The festival of Easter will be celebrated on the Sunday next following that day.

16. Now it is most necessary to the clear comprehension of the calendar, and for the prevention of numerous errors into which even well-informed persons frequently fall, to observe emphatically that not one of the principal terms used in this rule is to be understood in its usual and obvious meaning. The "spring equinox" does not mean the real spring equinox of the astronomers, the "moon" does not mean the moon which shines in the

firmament, nor does "full" moon mean a moon with a complete circular phase.

It often happens, accordingly, that the day appointed in the calendar for Easter Sunday is altogether different from the day on which that festival would fall, if the terms of the rule were used in their usual sense, and in such cases we find the newspapers filled with indignant imputations of error in the calendar, and visiting the public wrath upon those under whose direction it was compiled and computed.

17. We have shown that the commencement of spring, or what is the same, the moment of the spring equinox, is subject to variation in relation to the civil year, falling sometimes on the 20th and sometimes on the 21st March. The spring equinox of the calendar is, however, an imaginary equinox, which is supposed never to vary from the 21st March. Thus, even when the real equinox falls on the 20th March, the fictitious equinox of the calendar, by reference to which Easter is determined, still falls upon the 21st March.

18. The term "moon" in the rule signifies also a fictitious object, created or imagined expressly to suit the purposes of the calendar. Nor is the adoption of such a fiction, where it serves convenient purposes, unwarranted or unusual. Astronomers themselves have found their computations of the celestial phenomena materially facilitated and simplified by creating fictitious suns, moons, and planets, to which imaginary motions are imputed; and it may, therefore, be fairly contended that the creation of a fictitious moon for ecclesiastical purposes is not less justifiable.

The ecclesiastical moon is an object whose motions are governed by certain numbers, called the "golden numbers" and the "epacts." These numbers have a relation to the periodical changes of the real moon, in virtue of which the place of the ecclesiastical moon can never vary from that of the real moon beyond a certain limit. Thus the full of the one may differ by as much as two days from the full of the other, but not more.

A "full" moon, whether real or fictitious, is that which is presented at the middle of the interval between two successive new moons. Thus, if this interval be 29½ days, the full moon will take place in 14¾ times 24 hours after the moment of new moon. Now this is not the sense in which "full" moon is to be understood in the rule. To define exactly the sense of "full" moon in the rule, it will be necessary first to explain how the "age" of the moon is expressed in the language of the calendar.

19. The day upon which the moon is in conjunction with the sun, or, what is the same, upon which new moon takes place, is, properly speaking, shared between the old and the new moons,

If, for example, the conjunction take place at 3 o'clock in the afternoon, the interval of 15 hours since midnight belongs to the old, and the remaining 9 hours, until the next midnight, to the new moon. It is the custom, nevertheless, to call this the "first day of the new moon," and not the "last day of the old moon." Consequently, the "second day of the moon" is the day upon which it completes the first twenty-four hours of its age and commences the second twenty-four hours, and so on.

It may be objected that this mode of expressing the moon's age would lead to certain absurd consequences. It may happen, for example, that the moment of new moon may be only a second before midnight, in which case only *one second* of the entire day will belong to the new moon, and the day will, nevertheless, be called the "first of the moon."

Notwithstanding this, the first day of the moon is the day upon which the conjunction takes place, or the day upon which the new moon commences, no matter how late in the day, no matter how near its close the moment of such commencement may happen to be.

20. By the day of "full" moon in the rule, is then to be understood, not, as might be expected, the day upon which the middle of the interval between new moon and new moon falls, but the 14th day of the (ecclesiastical) moon's age; that is, according to what has been just explained, the day upon which that moon terminates its 13th and begins its 14th, twenty-four hours.

21. Thus it appears that the day of the full moon, by which the date of Easter-day is fixed, is not only not that of the full moon visible in the heavens, nor of the fictitious moon imagined by astronomers to define the average place of the real moon, but it is not even the day on which the fictitious ecclesiastical moon itself is full. In fine, the use of the term "full" in the rule given in the Book of Common Prayer is altogether incorrect, whatever sense may be attached to the term moon, and the rule ought to be expressed as follows:—

Find the day on or next after the 21st March upon which the ecclesiastical moon attains the 14th day of its age. The Sunday which next follows that day will be Easter-day.

Now, provided that the ecclesiastical moon be understood, this rule (after the explanation given above of the mode of expressing the age of the moon) is clear and definite.

It will be observed, that, according to the terms of the rule, if the 14th day be Sunday, Easter-day must be the following Sunday; but the 21st of March may itself be the 14th day.

It remains, therefore, only to explain the conditions which define the fictitious object which we have here called the ECCLESIASTICAL MOON.

22. Let it be remembered that the astronomical year consists of 365 days, 5 hours, 48 minutes, and 48 seconds, and that a lunar month varies in length from about 29¼ days to 29¾ days, its average length being exactly 29 days, 12 hours, 44 minutes, and 3 seconds.

It will appear from these numbers that 19 astronomical years consist of about

D.	H.	M.	S.
6939	14	27	12,

while 235 average lunar months consist of about

D.	H.	M.	S.
6939	16	31	45.

It appears, therefore, that 235 average lunar months exceed 19 astronomical years by only 2 hours, 4 minutes, and 33 seconds.

It follows from this, that if the course of time be resolved into a succession of periods, or *cycles*, of 19 astronomical years, the same phases of the moon which are presented in any year of one cycle will be reproduced in the corresponding year of the next cycle, on the same days, but 2 hours, 4 minutes, and 33 seconds later. If, therefore, the dates of the phases, those of the new moons for example, in each successive year of any one such cycle be ascertained, either by immediate observation or by calculation, their dates in the successive years of the next cycle will be on the same days, but 2 hours, 4 minutes, and 33 seconds later.

If, therefore, time were counted by astronomical years, and if the period of the lunar changes were always equal to the average lunar month, the days of new moons of any one cycle of 19 years being ascertained, the days of the new moons of every succeeding, and of every preceding cycle, would be known.

23. But time is not counted by astronomical years, and the period of the lunar phases is not always the same, and therefore this reproduction of the series of lunar phases, or corresponding days, will not take place.

Unlike the astronomical year, the civil year is not constantly of the same length. It consists, as has been already explained, sometimes of 365, and sometimes of 366 days. Neither is a cycle of 19 successive civil years always of the same length. Such a cycle contains sometimes only five, and sometimes four, leap years, and consists, therefore, sometimes of 6940, and sometimes of 6939 days. It, therefore, sometimes exceeds a cycle of 19 astronomical years by nearly a quarter of a day, and sometimes falls short of such a cycle by more than three-quarters of a day. If four successive cycles of 19 civil years be taken, three of them will exceed one astronomical year by something less than a quarter of a day, and the fourth will fall short of an astronomical year by something more than three-quarters of a day. The total length of the four successive cycles of 19 civil years will be as nearly as possible equal to four cycles of 19 astronomical years.

Thus it is evident that the civil year, though variable in length, oscillates alternately on one side and the other of the astronomical year; and, in like manner, the cycle of 19 civil years, which is also variable by one day, oscillates at each side of the cycle of 19 astronomical years. The civil year and the civil cycle are alternately overtaking and overtaken by the astronomical year and cycle, and their average lengths are respectively equal in the long run to the average length of the latter.

In like manner, the lunar month is subject to a certain limited variation, so that the phases of the real moon are alternately overtaking and overtaken by those of the average moon.

24. Now let us imagine a fictitious moon to move round the heavens in the path of the real moon, but with such a motion that its periodical phases shall take place in exact accordance with the civil years, and with the cycles of 19 civil years, in the same manner as the phases of the real moon recur in the succession of astronomical years, and in the cycles of 19 astronomical years. Such a fictitious moon is then the ecclesiastical moon, and is the moon whose phases are predicted in the calendar.

It will be evident from all that has been explained, that this ecclesiastical moon will alternately pursue, overtake, and outstrip the real moon, and be pursued, overtaken, and outstripped by it; that they will thus make together their successive revolutions of the heavens, and that they will never part company, nor either outstrip or fall behind the other beyond a certain distance, which is limited by the extent of the departure of the civil from the astronomical year, and by that of the real from the average lunar month.

25. For the purposes of the calendar, therefore, the course of time is supposed to consist of a succession of cycles of 19 civil years, and it has been agreed that each such cycle shall commence with a year the first day of which shall be the last day of the moon's age, or, what is the same, the day on which the age of the succeeding moon is 0.

The number which marks the place of any year in the cycle to which it belongs is called the GOLDEN NUMBER of the year. Thus when we say that the Golden Number of the year 1855 is 13, we mean that the year 1855 is the 13th year of the cycle to which it belongs, and it may be thence inferred that the first year of the cycle was 1843.

26. The age of the ecclesiastical moon on the first day of the first year of the cycle being known, its age upon the first day of

each succeeding year of the cycle may be determined. The number which expresses the age of the moon on the first day of any year of the cycle is called the Epact of that year.

The series of Epacts corresponding to the Golden Numbers of the years of a cycle are given in the following table:—

Golden Number .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Epact . .	0	11	22	3	14	25	6	17	28	9	20	1	12	23	4	15	26	7	18

27. The age of the ecclesiastical moon on the first day of any year being thus known by the Epact, which, as well as the Golden Number, is given in the Almanack, the age of the moon for every day of the same year can be ascertained, and by this means the date of Easter, according to the conditions of the rule, may be determined.

28. To show the application of the Golden Numbers and Epacts, and the departure of the ecclesiastical moon from the real moon, let us take for example the year 1855. The Golden Number being 13, the Epact, as appears by the above table, will be 12, and consequently, on the 1st of January the ecclesiastical moon will be in its 12th day. Its first day was, therefore, the 21st of December. Now, by referring to the lunar tables given in the almanacks, it will be found that the age of the real moon at the midnight which commenced the 1st of January, was 12 days 2¼ hours, and consequently the real moon was new on the evening of the 19th of December, at three-quarters of an hour past 9 o'clock.

It appears, therefore, that in this case there is a difference of two days between the real and ecclesiastical moons.

29. It is the ecclesiastical moon which alone figures in the calendar, and by the phases of which the date of Easter is governed: let us now see within what limits the variation of that festival, and consequently of all the other moveable feasts which depend on it, are confined.

30. It appears by the rule, rightly interpreted, that Easter will be the first Sunday after the 14th day of the ecclesiastical moon which occurs next after the 20th of March.

The earliest date of Easter compatible with these conditions would be when the 14th day of the ecclesiastical moon would fall on the 21st of March, and that the 21st of March itself should fall on a Saturday. In that case the following day, that is, the 22nd of March, would be Easter Day. Earlier than this the festival of Easter cannot fall, consistently with the rule laid down by the Church.

This contingency actually occurred in the year 1818. Its occurrence is, however, as may be imagined, very rare. Thus for three centuries, before 1818, it only happened three times, viz., in 1598, in 1693, and in 1761, and it will not happen again until 2285.

31. That Easter should be celebrated on the latest day which is permitted by the rule, it would be necessary that the 14th day of the ecclesiastical moon should be as late as possible after the 20th March, and that it should fall upon Sunday. To be as late as possible, it would be necessary that the 20th March should be itself the 14th of the moon. In that case the 14th of the next moon would fall upon the 18th April, which being by the supposition Sunday, Easter-day will by the rule be the following Sunday, that is the 25th April. Later than this Easter cannot fall, consistently with the rule laid down by the Church.

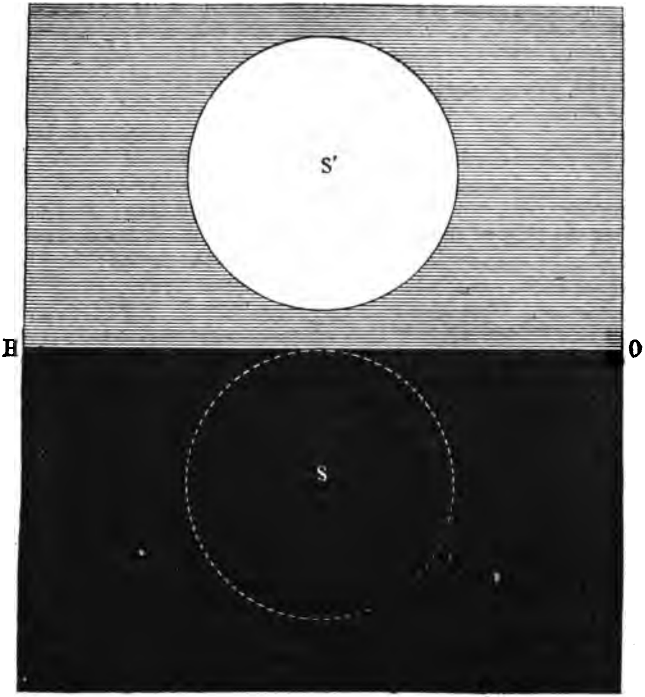
This contingency last occurred in 1734, and will next happen in 1886. It occurred in 1666 and will occur in 1943, in 2038, in 2190, &c.

Thus it appears that Easter-day may fall upon any of the 35 days, which are included between the 21st March and the 26th April, but that it cannot be earlier than the 22nd March, nor later than the 25th April.

32. The moon, the phases of which determine Easter, is called the Paschal Moon, and it is most important to bear in recollection that it is not the real visible moon of the heavens, but is the fictitious or imaginary moon called the Ecclesiastical Moon.

As the 14th day of the paschal moon cannot be earlier than the 21st March, nor later than the 18th April, it follows that the first day of that moon cannot be earlier than the 8th March, nor later than the 5th April.

Fig. 2.



COMMON THINGS.

THE ALMANACK.

CHAPTER II.

33. Paschal moon sometimes gives a different Easter from real moon.—34. Occasion of public controversies.—35. Professor De Morgan points out error in Act of Parliament.—36. Other moveable Feasts.—37. Extract from De Morgan's Book of Almanacks.—38. Whit-Sunday.—39. The Indiction.—40. Solar Cycle.—41. To find the year of the current solar cycle.—42. Dominical or Sunday Letter.—43. How affected by Leap-year.—44. Sunday Letter of the year 1 A.D.—45. To find Sunday Letter for any year.—46. Eras.—47. Julian Period.—48. Its commencement determined.—49. Its use in chronology.—50. Contents of the Calendar.—51. Aspect of the Heavens.—52. Times of rising and

setting of celestial bodies.—53. Distortion produced by the atmosphere.—54. Other effects.—55. True and apparent sunrise.—56. The sun seen before it rises.—57. Conventional meaning of the terms sunrise and sunset.—58. Refraction.—59. The Equinoxes—60. Day and night rarely of the same length.—61. How modified by refraction.

33. Since the dates of the corresponding phases of the real and ecclesiastical moons never differ one from the other by more than two days, and generally by still less, it happens most commonly that the 14th of the paschal moon and the full of the real moon fall in the same week, and in all such cases the date of Easter-day would be the same, whether it be determined by the one moon or the other. But they may and sometimes do fall in different weeks. Thus the full of the real moon may fall on a Friday or Saturday, while the 14th of the paschal moon falls on Sunday or Monday. In that case the date of Easter determined by the paschal moon will be a week later than if it were determined by the real moon.

On the other hand the 14th of the paschal moon may fall on Friday or Saturday, while the full of the real moon falls on Sunday or Monday. In that case the date of Easter, as determined by the paschal moon, would be a week earlier than its date determined by the real moon.

34. Whenever this discordance arises between the dates of Easter, as it would be determined if the real moon presided over it, and as it is determined by the ecclesiastical moon, the public press teems with diatribes either against the astronomers for misdirection of the computers of the almanacs, or against the computers for running counter to the lunar tables of the astronomers. As examples of this may be mentioned the year 1798, in which by the dictates of the real moon Easter should have fallen on the 1st April, but the ecclesiastical moon postponed it to the 8th; the year 1818, in which the real moon would have assigned it to the 29th March, but the ecclesiastical moon threw it back to the 22nd March, and the year 1845, in which the ecclesiastical moon placed Easter on the 23rd March, while the real moon would have postponed it to the 30th.

35. It was on the last mentioned occasion that the questions raised, and the disputes which prevailed, produced two remarkable essays on the subject of the Calendar and its history, by Professor De Morgan, which were published in the "Companion to the British Almanack for the years 1845 and 1846." In these articles were for the first time exposed some glaring errors committed by the British Legislature in the Act of Parliament (24 Geo. II., cap. 25, A.D. 1751), which at the time of the change of style

regulated the calendar, and supplied those rules and explanations which are still prefixed to the Book of Common Prayer of the Established Church. Professor De Morgan showed that the Legislature committed the error of taking the real moon of the heavens, as that by the phases of which Easter was to be determined, although the authorities from which they borrowed their rules, and which it was their intention to follow, most expressly disclaimed the celestial moon, and even showed the objections against taking it for the determination of the date of Easter. But the blunders did not end here. The professor further showed that not only the British Parliament, but astronomers themselves, and even many authors who had written expressly on the calendar, were altogether ignorant of the fact that it was not the day of the full, even of the ecclesiastical moon, but the 14th day of that moon's age, by which Easter was to be determined. Nevertheless, as the terms of the rule for determining Easter, properly understood, were correct, although the explanations and commentaries appended to them by the Legislature were erroneous; and as it was the evident intention of the Act to adopt the same method of determining the date of Easter as was used in the Roman Catholic Church; the computers of the almanacks were not misled by the wrong explanations, but continued to fix Easter as it was fixed in the Roman Church, and as in fact it was intended to be fixed in the Church of England.

36. The conditions which determine from year to year the date of Easter being well understood, the dates of other moveable feasts, all of which have fixed relations to Easter, will be determined. Some of these come before, others follow, Easter. As Easter, therefore, advances or recedes in date, it pushes forward the latter, and draws after it the former.

37. The following short explanation of the moveable feasts of the Church, and their dependance on Easter, which we borrow from Professor De Morgan's "Book of Almanacks," cannot be improved:—

"In the English nomenclature Easter Sunday has always the *six* Sundays in Lent immediately preceding, and the *five* Sundays after Easter immediately following. Of these the nearest to Easter before and after are *Palm* Sunday and *Low* Sunday; the farthest before and after are *Quadragesima* (first in Lent), and *Rogation* Sunday (fifth after Easter). Preceding all these are, in reverse order, *Quinquagesima*, *Sexagesima*, *Septuagesima*: and following them in direct order, are the Sunday after *Ascension* (Holy Thursday, Thursday five weeks after Easter), *Whit* Sunday and *Trinity* Sunday. So that Easter Sunday, as it takes its course through the almanacks, draws after it, as it were, *nine* Sundays, and pushes *eight* before it, all at fixed denominations. Looking farther back, every Sunday preceding Septuagesima, but not preceding the fixed day of Epiphany (Jan. 6th) is named as of *Epiphany* or after *Epiphany:* the least number of Sundays after Epiphany is one, the greatest number six. Looking farther forwards, all the Sundays following Trinity are named as *after* Trinity, in succession, until we arrive at the nearest Sunday (be it before or after) to St. Andrew's Day (Nov. 30th), which is the first Sunday in *Advent.* The least number of Sundays after Trinity is twenty-two; the greatest, twenty-seven. From thence, up to Christmas Day, exclusive, the Sundays are named as in *Advent*, and from Christmas Day to Epiphany, exclusive, they are named as Christmas Day, or as the first or second Sunday after Christmas."

38. The name WHITSUNDAY, or WHITE-SUNDAY, given to the festival of the Pentecost, is taken from an old custom of candidates for baptism, or for the first communion, wearing white dresses on the occasion, a custom still observed by females in Catholic countries.

39. In all almanacks a certain number is found connected with the year, called the INDICTION.

The Indiction is a period of fifteen years, having no reference to any religious observance or commemoration, nor any correspondence with astronomical phenomena. It was a conventional division of time, which was first established in the Roman empire and its dependencies, in the time of Constantine, and the origin of the name is unknown. It has been conjectured, that Constantine, desiring to discontinue the Pagan methods of reckoning time by Olympiads, which were periods of four years, and finding besides a longer division more convenient, established the Indiction.

The Indiction, unlike the periods marked by the golden number and the epact, had no relation to religion, but was used in the courts of law and in the fiscal administration of the empire by Constantine and his successors, and was continued under the Popes.

The point of departure of the Indictions was finally fixed by Gregory VII. to be the first day of the year 313, and calculating back from that, it would follow that the first year of the Christian era was the fourth year of the current Indiction. If then it be desired to find the numerical order of any proposed year since Christ in the current Indiction, it is only necessary to add 3 to it, and divide by 15, the remainder will be the sought number, and will be the Indiction of the proposed year. Thus, to find the Indiction of the year 1855, we add 3, which gives 1858, and dividing by 15 we find the remainder 13, which is the Indiction.

40. A common year of 365 days consists of 52 weeks and 1 day. It follows, therefore, that such a year is always followed by one which begins one day later in the week. If seven such years followed each other in uninterrupted succession, their first days would be the seven successive days of the week.

But a leap year consists of 52 weeks and 2 days; therefore, the first day of the year which succeeds it will be two days later in the week than that of the leap year. Since in seven successive years there *must* be one, and *may* be two leap years, it follows that the first days of the years included in such a period will not include all the days of the week.

To find the interval which must elapse between two years, each day of which will fall upon the same day of the week, it will be evidently necessary to find a number of years which will consist of an exact number of weeks. If there were no leap years, this number would evidently be 7, since the odd day which is contained in each year, seven times repeated, would make up a week, so that 7 years would consist of 4 times 52 weeks and 1 week, that is 209 weeks exactly. But the recurrence of a year of 366 days every fourth year prevents this.

Four years consist of 208 weeks and 5 days. It will be necessary, therefore, to find how often this interval must be repeated to make a complete number of weeks; or, what is the same, how often five days must be repeated to make a complete number of weeks. Now this is evidently 7 times, which will make up 5 complete weeks. If 4 years, therefore, be repeated 7 times, we shall obtain a number of years which will be also an exact number of weeks. But this number of years is 28, and it consists of 7 times 208 weeks, together with five weeks, making in all 1461 weeks.

After every successive period of 28 years, therefore, the same days of the year will fall upon the same days of the week.

This period of 28 years is called the SOLAR CYCLE.

41. The first year of the Christian era being taken to be the tenth of the current solar cycle, it follows, that to find the numerical order of any proposed year in the current solar cycle, we must add 9 to the year, and divide by 28; the remainder, if any, will be the order of the year. If there be no remainder, the year will be the last, or the 28th of the current cycle. Thus, for example, to find the order of the year 1855 in the solar cycle, adding 9, we have 1864, and dividing by 28, we obtain the remainder 16, showing that 1855 is the 16th year of the cycle, and the first year of the present cycle was therefore 1840.

42. The **Dominical, or Sunday letter**, which appears prefixed to the calendar, is an expedient by which the days of the week, which fall upon the successive days of any proposed year, past or future, may be determined. This expedient has a close relation with the solar cycle just explained.

If the general calendar usually prefixed to the Book of Common Prayer of the Established Church be referred to, it will be seen, that in the column which follows that of the numbers expressing the days of the month, the first seven letters of the Alphabet, A, B, C, D, E, F, and G, are annexed, and are continually repeated, for every successive series of seven days to the end of the year; the intercalary day of the 29th of February, in the case of a leap year, being, however, past over, and the letter which succeeds that annexed to 28th February being annexed to 1st March, as it would if the year were a common year of 365 days.

Now, if these seven letters be supposed to express the seven successive days of the week upon which the first seven days of the year fall, they will express equally the days of the week upon which all the succeeding days of the year fall, when it is a common year of 365 days, which we shall for the present suppose it to be, and the same letter throughout the year will everywhere express the same day of the week. Thus, if the 1st January fall on Sunday, the letter A, which is annexed to the 1st January, being also annexed to every seventh successive day to the end of the year, all these days must be Sundays.

In the same manner, the letter B being annexed to the 2nd January, that day being Monday, the same letter B will be found after every seventh succeeding day to the end of the year, and, therefore, all such days having B annexed will be Mondays.

It will be evident that like inferences will be applicable to the days marked by the other letters, and that similar consequences would follow if the 1st January were supposed to fall upon any other day.

Whatever, therefore, be the day from the 1st to 7th January, inclusive, upon which Sunday may happen to fall, the letter found annexed to that day will be found annexed to all the succeeding Sundays in the year; and consequently, if the day of the first seven on which the Sunday falls be known, the letter annexed to it will make known without further computation all the Sundays in the year.

This letter has therefore been called the **Dominical, or Sunday letter.**

43. But we have here supposed the year to be a common year of 365 days. If it be a leap year, the case will be different. In that case the letter which is annexed to the 1st March, will

express a day of the week one day later than that which it expressed before the 29th February, and the same will consequently be true of all the other letters. Thus, if the 22nd February, to which D is annexed, were Monday, all the other days, from 1st January to 28th February, to which D is annexed, would also be Mondays, and consequently the 28th February, to which C is annexed, must be Sunday, and therefore the 29th, to which no letter is annexed, must be Monday, and therefore 1st March, to which D is annexed, must be Tuesday, and all the succeeding days, to the end of the year, to which D is annexed, must be Tuesdays. Thus, in a leap year, if D express Mondays before the 29th February, it will express Tuesdays after that day, and, in general, each letter after the 29th February, will express the day of the week which succeeds that which is expressed before the 29th February.

It follows, therefore, that the Sunday letter in a leap year after the 29th February, is the Saturday letter before it, and is, consequently, the letter of the alphabet which precedes the Sunday letter at the beginning of the year. Thus, if the Sunday letter before 29th February be C, the Sunday letter after it will be B, if D it will be C, and so on. If the Sunday letter before 29th February be A, it will be G after it.

A leap year, therefore, has two Sunday letters, the first applicable to the part before, and the other to the part after, the 29th February.

44. It has been supposed that the birth of Christ took place on the Sabbath of the Jews, and consequently on the day now called Saturday. Since 1st January is the seventh succeeding day, it follows that the first day of the first year of the Christian era was Saturday, and consequently the Sunday letter of the year 1 A.D. was B.

45. Since a common year consists of 52 weeks and one day, it follows that the first and last day of such a year will fall upon the same day of the week, and that the first seven days of the next year will fall upon the week days which immediately succeed those upon which they fell in the preceding year. This will supply an easy rule, by which, when the Sunday letter of any year is known, those of all succeeding years may be at once found without calculation.

Let us suppose that the 1st January, in a certain year, is Sunday. The Sunday letter will then be A for that year. The year being supposed to be a common year, its last day will also be Sunday, and therefore the first day of the next year will be Monday, and the seventh, Sunday. The Sunday letter of that year will then be G.

I like manner it may be shown that the Sunday letter of the next, being a common year, will be F, and in fine, in general, the Sunday letter of a year which succeeds a common year will be the letter which precedes the Sunday letter of the year before.

The same will be true when a leap year is succeeded by a common year, only in that case the Sunday letter of the latter will be that which precedes the Sunday letter of that part of the leap year which follows the 29th February.

These observations will be illustrated by the following table of Sunday letters of the years 1840 to 1860:—

Years.	Sunday Letters.	Years.	Sunday Letters.	Years.	Sunday Letters.
1840	E D	1847	C	1854	A
1841	C	1848	B A	1855	G
1842	B	1849	G	1856	F E
1843	A	1850	F	1857	D
1844	G F	1851	E	1858	C
1845	E	1852	D C	1859	B
1846	D	1853	B	1860	A G

46. It is known to every one that different nations count their years and refer their historical events to different epochs, or ERAS,[*] as the points of departure have been called.

47. As may be easily conceived, much confusion arises from this cause. To compare together historical dates which refer to different eras, it is necessary to make a calculation based upon the interval between the eras to which the dates are severally related. It has therefore been considered to be a matter of great convenience to historical students in general to have some fixed era of common reference, to which dates referred to other eras may be reduced, so as to form a common standard of historical and chronological time, as the first day of the year does in the case of civil time applied to shorter intervals. A period has been accordingly agreed upon for this purpose, derived from the combination of the three cycles, the Metonic, the Solar, and the In-

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[*] Etymologists differ as to the origin of this word. The Latin *æra* is by some derived from the plural of *æs*, brass or money; in the plural signifying also counters. Others derive it from the Greek; others from the Arabic; and according to others, it is composed merely from the initials of the Latin sentence *Ab exordio regni Augusti*, "from the beginning of the reign of Augustus."

diction, which have just been explained. To find a certain number of years, which is at the same time an exact multiple of each of these cycles, we have only to multiply together the number of years in each of them. Thus, if we multiply 19 by 15, we shall obtain 285 years, which consists of exactly 15 cycles of Meton and 19 Indictions. Again, if this last number, 285, be multiplied by 28, we shall obtain 7980 years, which consists of exactly 285 solar cycles, or of 420 Metonic cycles, or, in fine, of 532 Indictions.

This interval of 7980 years was proposed as a common historical and chronological period, by the celebrated historian Joseph Scaliger, who gave it the name of the JULIAN PERIOD.

48. For the purposes of history and chronology, it was not, however, enough to suggest such a cycle. It was necessary to discover its natural and proper starting-point or era. Supposing that we are now at some point in such a current cycle, what is that point?—or, which is the same thing, what was the first year of the period?

Since the period proposed consists of an exact number of cycles of Meton, an exact number of Indictions, and an exact number of solar cycles, it is evident that its natural and proper commencement must be the year which was at the same time the first of a Metonic cycle, the first of a solar cycle, and the first of an Indiction. Now, as we know the first years respectively of each of these current cycles, it is only necessary to count each of the three back into past times until we find a year which is at once the first year of each of the three. That year will then be the first year of the current Julian period.

This is precisely what Scaliger did. He took, for example, the first year of the then current Metonic cycle, and counting back from 19 years to 19 years, made a table of the first years of each cycle, expressed with reference to the Christian era. He then took in like manner the first year of the current Indiction, and by counting back from 15 years to 15 years, made a like table of the dates. He then took the first year of the current solar cycle, and made a similar table. In these tables he sought and found the year before Christ which was a first year of the Metonic cycle, a first year of the Indiction, and a first year of the solar cycle. This was the year 4713 B.C.

He therefore fixed the commencement of the Julian period at the year 4713 B.C., or, to be still more precise, on the 1st of January in that year, at the moment of mean noon for the meridian of Alexandria, that being the place at which the observations of Ptolemy were made, and to which the tables of that celebrated astronomer and observer were related.

49. Ideler, in his "Handbuch der Mathematischen und Technischen Chronologie," in reference to this convention of Scaliger, says that by its employment light and order were for the first time let in upon the obscurity and confusion in which ancient history and chronology were involved.

Since the year of the birth of Christ was then the 4713th of the Julian period, the order of any later year of the Christian era in the Julian period will be found by adding 4713 to the year. Thus, for example, the year 1855 is the 1855 + 4713 = 6568th year of the current Julian period.

To find the order of any year before Christ in the Julian period, it will be only necessary to subtract the year from the order of the year 1 A.D. in the Julian period, that is, from 4714. Thus, knowing that the date of the invention of the Metonic cycle was 432 B.C., its date in the current Julian period was

$$4714 - 432 = 4282.$$

50. The Calendar, properly so called, is constructed differently in different almanacks. In most, if not all, it gives for each day the times at which the sun and moon rise and set, and the time at which the latter passes the meridian; the moon's age, and the sun's declination. We shall briefly notice each of these useful indications.

51. The hours at which the heavenly bodies rise and set upon the same day at different places are different. This arises either from the different places being at different distances from the pole of the earth—that is, having different latitudes, or being on different meridians of the earth, that is, having different longitudes. In either case the heavens, as seen from them, being viewed from different stations, will be seen under different aspects. Celestial objects, which will be invisible from one place, will be visible from the other. The heavens may be considered as a panorama, and the earth as a vast circular gallery or series of galleries in its centre, to which a slow motion of revolution is imparted, so as to exhibit to every spectator every part of the great canvas of the heavens in succession. The parts of the heavens seen by spectators, differently situated in these central galleries, will obviously be different. An object which will be just coming into the view of some,—that is, rising,—will be in full front of others,—that is, on their meridian,—and will be disappearing from others, that is setting. Spectators placed in the upper galleries, that is, in northern latitudes, will look down upon objects to which spectators in the lower galleries, that is, in southern latitudes, will look up, and which spectators in the middle galleries, that is, between the tropics, will see directly before them.

52. Now all these circumstances must be taken into account if we desire to predict by calculation the portion of the heavenly panorama which will be presented to the view of spectators at any given place, at any given time, and the objects, whether they be sun, moon, or planets, which may happen to be upon that portion of the panorama. And this is precisely what astronomers do when they compute those tables of the rising and setting, and the meridional transits of these objects. Without going into the technical details upon which such computations are based, it will be evident that if the position of a place upon the earth's surface be given, the aspect under which the heavens will be seen from that place, shifting from hour to hour, can be ascertained beforehand, and the positions in which all objects upon it will be seen at any given hour, minute, and second, or the hour, minute, and second at which they will have any proposed position on the visible hemisphere, can be certainly and exactly predicted.

These, then, speaking generally, are the principles upon which the numbers given in those columns of the calendar to which we have just referred have been computed.

53. We see this vast spectacle, however, not immediately, but by the intervention of a medium which produces upon it certain optical effects. Our station is at the bottom of an ocean of transparent fluid, about fifty miles deep. This fluid is called the atmosphere, and it is by looking upwards through it that we see the heavens. Such a medium, however clear and translucent it may be, has always a certain distorting effect upon the objects seen beyond it. It is as though we saw the heavens through a thick sheet of glass, the external part of which is convex, and the internal concave. The celestial objects are by this, therefore, more or less distorted in form, and disturbed in their position in relation to the horizon. It is true that owing to the air being a very light and attenuated fluid, and especially so at great heights, this distortion and derangement are so inconsiderable, that except in particular cases they can only be perceived by astronomical observers, and by them only with the aid of good instruments, by which very small differences of direction and position can be ascertained.

Nevertheless, there are cases in which this curious atmospheric influence is palpable to the sight. Every one who has observed the fiery orb of the sun, or that of the full moon just before setting or soon after rising, when they are seen through a thick mass of air at low altitudes, will have noticed that they do not appear round as they ought to be, but oval, the longer diameter of the oval being horizontal. Now this is a distortion of their form produced by the mass of air through which they are seen.

54. Another effect of transparent media, and the air among the rest, is to change the apparent direction of objects seen through them. Every one can verify this by looking at distant objects through pieces of glass having curved or angular surfaces. They are never seen in their true directions.

The effect produced by the air is to make all objects appear at greater altitudes than they really have, or than those at which they would be seen if the air had not been interposed. The effect of this is greater at low than at high altitudes. When an object is very near the horizon, which it is just before it sets or just after it rises, its apparent altitude is greater than its true altitude by something more than half a degree: now half a degree is equal to the apparent diameter of the sun or moon.

If an object, therefore, were in such a position, that without the interposition of the atmosphere it would be seen exactly on the horizon, as when it rises or sets, the atmosphere would cause it to appear at more than half a degree above the horizon.

In the same manner, if an object were half a degree below the horizon, and therefore having already set or not yet risen, and being consequently invisible, it would by the effect of the atmosphere be seen above the horizon, and would therefore be visible.

It is evident, therefore, that the atmosphere makes all objects appear to rise sooner and to set later than they would rise or set if the atmosphere were absent; and consequently, in calculating the rising and setting of the sun and moon, this must be taken into account.

55. It may be asked whether it be really true, as would appear from what has been just explained, that the air enables us to see the sun before it has risen, and after it has set? There can be no doubt that such is the case, and that at the moment indicated in the almanack, as that of sunrise or sunset, the sun is really below the horizon and not upon it. These circumstances, which are not only interesting in themselves, but affect in a very considerable degree the calculations of the almanack, will be rendered more easily intelligible by reference to figs. 1 and 2.

The horizon is represented by the line H O, the dark part being below, and the shaded part above it. The moment of sunset or sunrise is, properly speaking, that at which the centre of the sun's disc is seen upon the horizon H O, and, when consequently, the horizon would pass across the middle of the disc, one half of which would be above it, and therefore visible, and the other half below it, and therefore invisible, as shown at S, fig. 1.

The moment at which the centre of the sun would be seen at S, fig. 1, in the absence of the atmosphere, is called the moment of TRUE SUNRISE or SUNSET, and for a long time this was the time of sunrise and sunset given in the almanacks.

The moment at which the centre of the sun's disc, seen as it is through the atmosphere, is at S, fig. 1, is called the moment of APPARENT SUNRISE or SUNSET, and is the time now given in the almanacks.

56. As we have already stated, the apparent altitude of objects on or very near the horizon is greater than their true altitude by more than half a degree. But the apparent diameter of the sun being itself about half a degree, it follows that the sun is elevated by the optical effect of the air to an altitude greater than its real altitude by more than its own apparent diameter.

If then we take a point S′, at a height above S, fig. 1, equal to that by which the atmosphere augments the apparent altitude, this height, S′ S, will be greater than the apparent diameter of the sun, and when the real centre of the sun's disc is at S, it will appear to be at S′, and the disc of the sun, instead of being seen at S, the horizon dividing it into two equal parts, will, in fact, be seen at S′, not only quite clear of the horizon, but with its lowest part more than a quarter of a degree above the horizon.

Let us take another case which is still more curious. Let the true position of the sun's disc, that is, the position it would have if there were no atmosphere, be that shown at S, in fig. 2, being that which it has the moment before it begins to rise, or the moment after it has completely set. In this position the disc just touches the horizon, and the depression of the centre of the disc below the horizon is a quarter of a degree. Now what is the effect of the atmosphere?—to make the centre of the disc appear to be more than half a degree higher, and consequently more than a quarter of a degree above the horizon. The disc, therefore, which is really altogether below the horizon, is in this case seen in fact altogether above it as shown at S′, fig. 2.

57. The terms SUNRISE and SUNSET are commonly used, as indeed most other terms are, in a loose and vague sense. The sun may be said to be in the act of rising from the moment at which the highest point of its disc begins to be seen until its lowest point just touches the horizon; that is, from the moment it has the position S, fig. 3, until it has attained the position S′. In the same manner it may be said to be in the act of setting from the moment it has the position S′, until it has sunk to the position S.

But in order to give a definite signification to the terms SUNRISE and SUNSET, it has been agreed to apply them to the moment at which the centre of the sun's disc is on the horizon, as it is shown at S, fig. 1. Thus the conventional moment of sunrise and sunset is intermediate between the actual beginning and end of the sun's appearance or disappearance.

All the observations which have been here made respecting the rising and setting of the sun are equally applicable to the rising and setting of the moon, the apparent diameter of which is equal to that of the sun.

The interval between the moment at which the sun or moon begins to rise or set, and that at which it has completely risen or set, varies in different places and at different seasons, but is generally something more than two minutes.

58. The optical property of the air, by which the effects above described are produced, is called refraction; and the displacement which is produced in the position of an object is called its refraction.

The refraction is greater or less according as the altitude is greater or less, and disappears altogether when the object is in the zenith, that is, when it is directly above our heads.

The effect, therefore, of refraction is to make the sun rise earlier and set later than it would if no atmosphere existed. The days are thus at all seasons rendered longer, and the nights shorter, than they would be if the earth were not surrounded by an atmosphere; and as the effect of refraction retards the setting and accelerates the rising by about two minutes, it increases the length of the day, and decreases that of the night by about four minutes; this, however, is subject to variation depending on the latitude of the place and the season of the year.

59. The equinoxes, as commonly understood, are those days in March and September on which the intervals of light and darkness are equal, the sun rising and setting at 6 o'clock.

Now any one may convince himself by reference to the columns of sunrise and sunset in an almanack that no such days ever exist.

Yet the very name of equinox is taken from the supposition of equal day and night. How then is the equinox to be understood, and from whence has it derived its name?

It may perhaps be supposed that although there be no case of day and night absolutely equal, the equinoxes may be those days in March and September in which the day and night are least unequal.

But if the columns of sunrise and sunset be examined in any almanack, it will be found that the day upon which the intervals of light and darkness are least unequal, precedes the day of the equinox in March and follows it in September, by one or two days.

This is so contrary to the commonly received notions that the point will require some explanation.

The sun's disc makes a circuit of the heavens in a year. Its position from March to September is such as to render the days longer, and from September to March such as to render them shorter than the nights.

At a certain moment on some day in each of these months, the sun's disc has such a position that if it were to remain stationary in that position, and if there were no atmosphere, sunrise and sunset would take place exactly at 6 o'clock, A.M. and P.M., and consequently the days and nights would be precisely equal, each being twelve hours.

The moment at which the sun's disc has this position, is that of the equinox.

60. Before the equinox in March, the position of the sun has a tendency to render the nights longer, and after it to render them shorter than the days.

Before the equinox in September, its position has a tendency to render the days longer, and after it shorter than the nights.

If on the day of the March equinox, the equinox take place exactly at noon, the sun will have a tendency for the preceding twelve hours to render the night longer, and, for the succeeding twelve hours, shorter than the day. In that case, these effects will compensate each other, and if there were no atmosphere the day and night would be equal. But in this case sunrise and sunset would take place not at six o'clock, but a little later. The tendency of the sun for the twelve hours before noon being to render the nights longer than the days, the sun would not rise till after six, and its tendency during the twelve hours of the noon being to render the day longer than the night, the sun would not set until after six.

If the equinox of March take place in the forenoon, the tendency of the sun in the interval since the preceding midnight being to render the nights longer than the days, and its tendency in the longer interval until the next midnight being to render the days longer than the nights, the latter tendency will prevail, and the day would be longer than the night.

If the equinox of March take place in the afternoon, the contrary effects will ensue for like reasons, and the night would be longer than the day.

Similar observations will be applicable to the equinox of September, but with opposite results. If the equinox take place in the forenoon, the night will be longer than the day, and if in the afternoon, the day will be longer than the night.

It must not be forgotten, however, that these conclusions are such as would follow only on the supposition that the effect of the atmosphere is excluded.

Thus it will be seen that, putting aside the consideration of atmospheric refraction, day and night could never be precisely equal, except in the rare case in which the equinox takes place at the moment of noon.

61. Let us now consider how these phenomena are modified by atmospheric refraction, which, as has been shown, increases the length of the day and decreases that of the night; and it must be observed that their effect is much more considerable than any which can arise from the moment of the equinox occurring either in the forenoon or the afternoon.

On the day of the March equinox, whether day and night be equal or unequal so far as depends on the position of the sun, the effect of refraction will be to cause the length of the day to be greater than that of the night, since its effect greatly predominates over any which the sun's change of position could produce.

On the preceding days, refraction has the same tendency, but then the tendency of the sun's position to render the night longer than the day is more considerable, and will be such as to balance or predominate over the effect of refraction either one or two days before the equinox. The consequence is, that the day upon which the intervals of light and darkness are either exactly equal or least unequal, will be either one or two days before the day of the equinox.

It may be shown precisely in the same manner that the day in September on which the intervals of light and darkness are either exactly equal or least unequal, will be one or two days after the equinox.

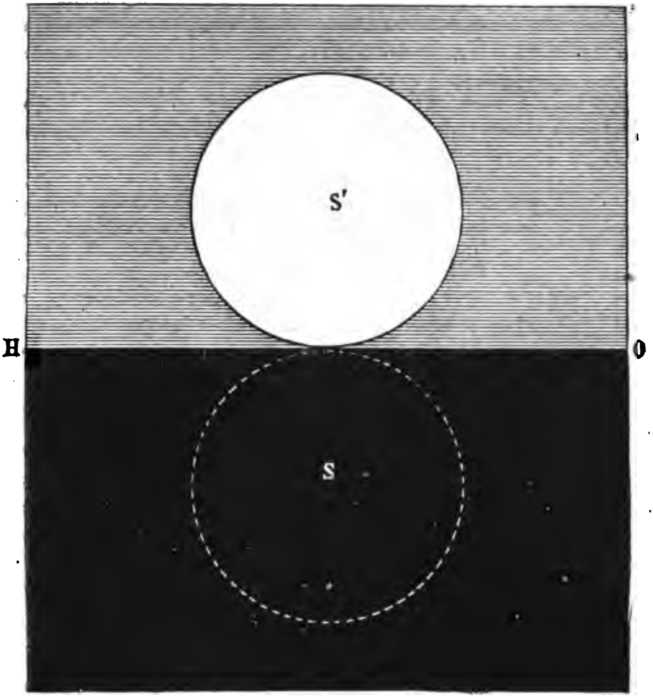
These observations may be easily verified by reference to the columns of sunrise and sunset in any almanack. Take for example that of 1854.

The March equinox took place at 20 minutes past 10 in the evening of the 20th. The day on which the intervals of light and darkness were least unequal was the 19th, upon which the sun rose at 8 minutes past 6, and set at 9 minutes past 6.

The September equinox took place at 13 minutes past 9 on the morning of the 23rd. The day and night were exactly equal on the 25th, when the sun rose at 51 minutes past 5, and set at 51 minutes past 5.

In these observations we have quoted the almanack as calculated for London, but similar consequences may be deduced from those computed for other places.

Fig. 3.



COMMON THINGS.

THE ALMANACK.

CHAPTER III.

62. Noon.—63. Clock time and sun time.—64. Declination of sun.—65. Tropics.—66. Solstices.—67. Dog days.—68. Why Midsummer is not the hottest season.—69. Unequal intervals between the equinoxes.—70. Signs of the Zodiac.—71. Their designations.—72. Tropics of Cancer and Capricorn.—73. Change of position of constellations.—74. Zodiac.—75. Ecliptic.—76. Other contents of Almanack.—77. Astronomical terms.—78. Conjunction.—79. Opposition.—80. Quadratures.—81. Morning and evening star.—82. Further illustrations.—83. Lunar changes.—84. When said to be gibbous.

62. In the daily course of the sun through the firmament, there are three important epochs, the beginning, the middle, and

the end, that is, sunrise, midday or noon, and sunset. The first and last of these having been fully explained, it remains to offer some observations on the second.

The hour of noon, or midday as commonly understood, is that at which a correctly regulated clock strikes twelve, or the moment at which the centre of the sun's disc passes the meridian, or the moment which divides the interval between sunrise and sunset into two equal parts. When these conditions come to be closely examined, however, they are found to be inconsistent one with another, the times which they severally express being in fact different.

63. It has been already explained in our Tract on "Time," that the moment at which the centre of the sun's disc passes the meridian is not that at which a correctly going clock strikes 12. The former is apparent, and the latter mean or civil noon. It is to the latter that the term noon or midday is commonly applied, and to which we shall here exclusively apply it.

Since, therefore, the moment at which the centre of the sun's disc each day passes the meridian is not the moment of noon, nor any fixed and invariable time either before or after noon, it is as necessary that the almanack should indicate from day to day what this time is, as that it should show the times of sunrise and sunset. In all good almanacks, a column is therefore appropriated to this, placed as it ought naturally to be between those which indicate sunrise and sunset. This column is variously headed, "equation of time," or "sun fast," or "sun slow," or "clock before sun," or "clock after sun," as the case may be. Whatever be the words at the head of the column, the numbers which are consigned to it are the number of minutes and seconds before or after twelve by the clock (supposed of course to be perfectly correct and to show civil or mean time*) at which the centre of the sun's disc passes the meridian.

This meridional transit of the sun's centre may vary from the hour of noon to the extent of more than sixteen minutes one way or the other.

If the almanack for 1854 be referred to, it will be seen that the meridional transit of the sun's centre took place in that year—

From 1st Jan. to 15th April . . .	in the afternoon.
,, 16th April to 14th June . . .	in the forenoon.
,, 15th June to 31st Aug. . .	in the afternoon.
,, 1st Sept. to 25th Dec. . . .	in the forenoon.
,, 25th Dec. to 31st Dec. . . .	in the afternoon.

The meridional transit of the sun's centre took place at the

* See Tract on "Time" (36).

moment of noon on 15th April, 14th June, 31st August, and 25th December, and this takes place every year on the same days, or nearly so.

Noon does not divide the interval between sunset and sunrise into equal parts, but the moment of the meridional transit of the sun's centre does so very nearly. Now, since this may vary to the extent of 16 minutes and 18 seconds from noon, it follows that the parts into which the day is divided by noon may differ in length to the extent of 32 minutes and 36 seconds.

64. In all almanacks a column is appropriated to the sun's declination. It is therefore necessary to elucidate this technical term.

On the days of the equinoxes the sun, at the moment of its meridional transit, has a certain altitude. But for the effect of atmospheric refraction, this altitude, subtracted from ninety degrees, would leave a remainder which would be exactly equal to the latitude of the place. Since astronomers have computed and published tables which show the refraction corresponding to each altitude, the refraction can be found in these tables, and being subtracted from the observed altitude of the sun, will leave a remainder which is its true altitude.

If the altitude of the sun after the March equinox be observed daily at the moment of its meridional transit, it will be found to exceed that which it had on the day of the equinox by a constantly increasing quantity. This excess, after the effects of refraction have been allowed for in the manner just explained, is called the SUN'S DECLINATION, the sun being said to DECLINE or fall from the position it had in passing the meridian at the equinox; and since, in this case, it declines from that position towards the visible celestial pole—that is, towards the north—it is said to have NORTHERN DECLINATION.

The meridional altitude will be found to increase continually until the June solstice, when it will exceed the altitude at the equinox by 23 degrees and 28 minutes. The meridional altitude of the sun having then attained its limit, begins to decrease, and with it, of course, decreases the declination, until at length, at the time of the September equinox, it becomes nothing, the meridional altitude being again what it was at the March equinox.

Now, during all this interval, from March to September, the meridional altitude of the sun is greater than it is at the equinoxes, and the declination is consequently all the time northern.

But if the same course of observation be continued, it will be found that after the September equinox the meridional altitude will become less, and will be less and less from day to day. The sun will then *decline* more and more to the *south* of its position at the equinoxes; that is, it will have SOUTHERN DECLINATION, and its meridional altitude will continually decrease, and consequently its southern declination will continually increase until the December solstice, when it will be 23 degrees 28 minutes, just what it was at the June solstice, only that it is now that distance south of its meridional altitude at the equinoxes, whereas in June it was north of that altitude.

After the December solstice the meridional altitude will gradually increase, and consequently the southern declination will gradually decrease until the March equinox, when the declination will become nothing.

All these periodical changes in the declination may be seen by referring to the column of the almanac appropriated to it.

65. Now there are certain circumstances connected with these changes which require especial notice.

It will be observed that the northern declination of the sun continually increasing after the March equinox until the June solstice, then ceases to increase, begins to decrease, and continues to decrease until it becomes nothing at the September equinox. The sun, therefore, continually moves from its position in March, and crosses the meridian at points more and more distant from that at which it crossed it in March, until at length at the June solstice it crosses it at a distance of 23 degrees 28 minutes from the point where it crossed it in March. After that the point where it crosses the meridian begins to go back towards the point where it crossed in March, and continues to go back until it returns at the September equinox, to the point where it crossed in March.

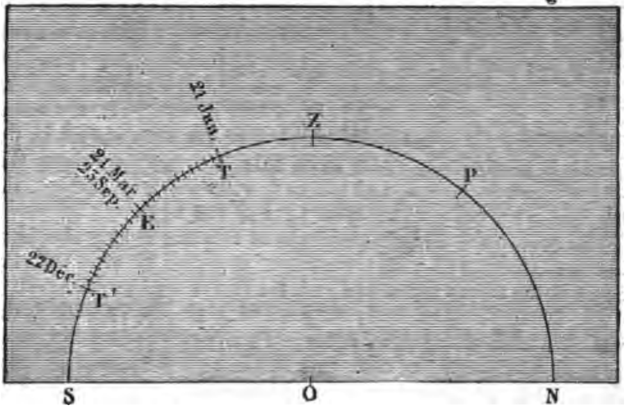
The same observations will be applicable to the points where it crosses the meridian from September to March, these points gradually receding southwards until the December solstice, and then returning back and resuming their position in March.

This will be more clearly understood by reference to fig. 4, where S N represents the horizon, S being the south, N the north, O the observer; S Z N the celestial meridian, E the point where the sun passes it at noon on the day of the equinox. Let us suppose that the equinoxes fall on the 21st March and 23rd September, and the solstices on the 21st June and 22nd December. After the 21st March the sun passes the meridian at points farther and farther above E until the 21st June, when it passes at T. After the 21st June it passes at points nearer and nearer to E until, on the 23rd September, it passes at E. After the 23rd September it passes below E lower and lower until, on the 22nd December, it passes at T′. After the 22nd December it passes at points higher and higher until the 21st March, when it passes at E.

The points T and T′ at which the sun attains its greatest distance from E, and at which, after having departed from E, it begins to return to E, are called the TROPICS from a Greek word *τροπή* (tropé), which signifies *a return.*

66. It is observed that when the sun arrives at these points T and T′, it pauses for some days without changing in any considerable degree its distance from E, and under these circumstances the hours of rising and setting continue to be sensibly the same. If, for example, the almanack be examined, it will be found that from the 10th to the 24th June the hour of sunrise does not change by more than two minutes, and that from the 13th to the 21st inclusive it does not change at all. In the same manner the hour of sunset remains the same from the 19th to the 22nd inclusive, and does not vary more than two minutes from the 17th to the 28th inclusive.

Fig. 4.



The same circumstances will be found to attend the sun when it passes the meridian at T′ in December.

Owing to this stationary position of the sun, and the consequent unchanging length of the days, these epochs are called the SOLSTICES, from a Latin word SOLSTITIUM, which denotes the *standing still of the sun.*

The June solstice is called the SUMMER SOLSTICE, and the December solstice the WINTER SOLSTICE.

They are respectively the days on which the sun attains the greatest and least meridian altitude which in the place for which the almanack is calculated it can attain, since it never can rise higher than T, or descend lower than T′ when on the meridian.

The days of the solstices are also respectively the longest and the shortest days of the year.

67. In almanacks generally the 3rd July and the 11th August are indicated as the first and last of the DOG DAYS. This comprises an interval of 40 days, which is generally the hottest part of the summer.

In the time of the ancient astronomers of Egypt and Greece, the position of the equinoctial points and the tropics which determine the limits of the seasons was different from what it is at present, and was such, that a remarkable star called Sirius, in the constellation called CANIS MAJOR or the "great dog," rose in the mornings immediately before the sun during the month of July, of which it was considered the harbinger, and whose calorific power was imagined to be increased by its influence. The idea that this star, the Dogstar as it was called, exercised such an influence, was no doubt countenanced by its extraordinary splendour, being by far the most brilliant of the stars visible in the northern hemisphere. The days, therefore, during which this star ushered in the sun, and led, as it were, his way through the heavens, were called CANICULAR DAYS or DOG DAYS.

The prevalence of canine madness at this season may also have had something to do with the name of dog days, or even with the name of the constellation to which the star in question belongs.

68. It might naturally be supposed that the days on which the sun rises highest and remains longest above the horizon ought to be the hottest, and that consequently the hottest interval of forty days should be the forty days which comprise twenty before and twenty after the summer solstice—that is, from the 2nd June to the 10th July. But this is just a month earlier than the interval which is found by observation and experience to be on an average of years the hottest part of the season. How then, it will be asked, can this be explained?

That the calorific effect of the sun is greatest on the day of the solstice is undoubtedly true; but it is easy to show that the day on which the sun imparts most heat is not the hottest day.

To explain this, so far as it depends on the position of the sun and the length of the days and nights, we are to consider the following circumstances:—

As midsummer approaches, the gradual increase of the temperature of the weather has been explained thus: The days being considerably longer than the nights, the quantity of heat imparted by the sun during the day is greater than the quantity lost during the night; and the entire result during the twenty-four hours gives an increase of heat. As this augmentation takes place after each successive day and night, the general temperature continues to increase. On the 21st of June, when the day is longest, and the night is shortest, and the sun rises highest, this augmentation reaches its maximum; but the temperature of the weather does not therefore cease to increase. After the 21st of June, there continues to be still a daily augmentation of heat, for the sun still continues to impart more heat during the day than is lost during the night. The temperature of the weather will therefore only cease to increase when, by the diminished length of the day, the increased length of the night, and the diminished meridional altitude of the sun, the heat imparted during the day is just balanced by the heat lost during the night. There will be, then, no further increase of temperature, and the heat of the weather will have attained its maximum.

But it might occur to a superficial observer, that this reasoning would lead to the conclusion that the weather would continue to increase in its temperature, until the length of the days would become equal to the length of the nights; and such would be the case, if the loss of heat per hour during the night were equal to the gain of heat per hour during the day. But such is not the case; the loss is more rapid than the gain, and the consequence is, that the hottest day usually comes within the month of July, but always long before the day of the autumnal equinox.

The same reasoning will explain why the coldest weather does not usually occur on the 21st of December, when the day is shortest and the night longest, and when the sun attains the lowest meridional altitude. The decrease of the temperature of the weather depends upon the loss of heat during the night being greater than the gain during the day; and until, by the increased length of the day and the diminished length of the night, these effects are balanced, the coldest weather will not be attained.

These observations must be understood as applying only so far as the temperature of the weather is affected by the sun, and by the length of the days and nights. There are a variety of other local and geographical causes which interfere with these effects, and vary them at different times and places.

69. Since the sun moves through one-half of the circumference of the heavens between the 20th of March and the 23rd of September, and through the other half between the 23rd of September and the 20th of March, in each half-year moving over 180° of the ecliptic (the name given to the apparent course of the sun over the firmament), it might be inferred that these two intervals must necessarily be equal. But if we take account of the days included in them respectively, we shall find that such is not the case.

The numbers of days in the two intervals in 1854, for example, were:—

20th March to 23rd Sept.		23rd Sept. to 20th March.	
March	11	September	7
April	30	October	31
May	31	November	30
June	30	December	31
July	31	January	31
August	31	February	28
September	23	March	20
Total	187	Total	178

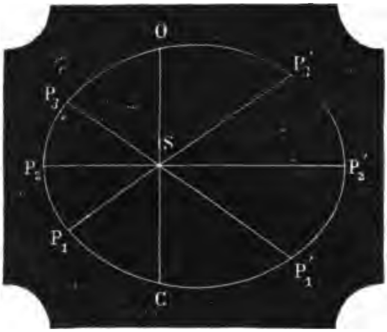
It appears, therefore, that the one exceeds the other by nine days.

Now, since in each interval the sun moves over the same space of the heavens, *i. e.* 180°, it follows, that its mean motion during the winter half-year must be faster than during the summer half-year, in the proportion of 187 to 178.

To explain this fact, it will be necessary to refer to the motion of the earth round the sun, which is the cause producing the apparent annual motion of the sun round the heavens.

The orbit or path which the earth follows in its course round the sun is not circular, but slightly oval. It may be supposed to be represented by P_2 O P'_2 C, fig. 5, S being the place of the sun nearer to one end, P_2, of the oval than to the other end, P'_2. The speed with which the earth would move if its path were a circle, with the sun in the centre, would be uniform; but in the oval, its distance from the sun varying, its speed will also vary, being greater at less, and less at greater distances. Thus, its speed at P_2, where it is nearest the sun, is greatest, and at P'_2, where it is most remote from the sun, least. The speed decreases continually while the earth moves from P_2 to P'_2, and increases continually while it moves from P'_2 to P_2. If the oval be divided into equal parts by the line P_2 S P'_2, the times of moving through each half of it will be equal; and if it had so happened that the earth should be at these two points, P_2 and P'_2, on the days of the equinoxes, then the summer and winter half-years would be exactly equal. But such is not the case. The earth, on the contrary, in

Fig. 5.



1854, was at the points C and O on the 20th of March and the 23rd of September, so that it moved from C through O to C, between the 20th of March and the 23rd of September, and from O through C to O, between the 23rd of September and the 20th of March. Now, not only is the latter segment of the oval shorter than the former, but the motion of the earth while passing over it is more rapid. On both accounts, therefore, the time of moving from O to C is less than the time of moving from C to O; and, accordingly, we find that the interval from the 20th of March to the 23rd of September is nine days longer than the interval from the 23rd of September to the 20th of March.

It may here be observed in passing as a curious fact, that the earth is nearer the sun at the winter than at the summer solstice, and it might therefore be supposed that the temperature of the seasons ought to be reversed. But the effect of this difference of distance is incomparably smaller than the effect due to the greater length of the day and the greater altitude of the sun, and these latter consequently predominate.

70. The sun moving in a year round the entire ecliptic, and therefore passing over 360°, moves over 30° per month. The ecliptic being conceived therefore to be divided into twelve equal parts of 30°, each of these parts is called a SIGN.

A certain zone of the heavens, extending to about 9° at each side of the ecliptic, is called the ZODIAC.

The zodiac, like the ecliptic, which runs along its middle, is conceived to be divided into twelve equal parts, called THE SIGNS OF THE ZODIAC.

The signs are supposed to begin at the point through which the sun passes at the March equinox, and to follow the course of the sun, so that the last in order of the signs is that through which the sun passes in the thirty days which precede the March equinox.

71. In ancient times the successive divisions of the zodiac which have been called signs, were occupied by certain conspicuous constellations or groups of stars, and each sign took its name from the constellation of which it was thus the place. It was and still is the custom to give names to constellations taken from animals, or mythological and historical personages. They have been generally called by their Latin names, which are given in the first column of the following table; the English names are given in the second, the symbol by which they are indicated in almanacks and calendars in the third. The days of the civil year upon which the sun enters the successive signs vary with the variation of the day of the equinox, the cause of which has been already explained. In the fourth column of the annexed table,

the days on which the sun enters them severally when the equinox falls on the 21st of March, are given.

Aries	Ram.	♈	21st March.
Taurus	Bull	♉	20th April.
Gemini	Twins	♊	21st May.
Cancer	Crab	♋	22nd June.
Leo	Lion.	♌	23rd July.
Virgo	Virgin	♍	23rd August.
Libra	Balance	♎	23rd September.
Scorpio	Scorpion	♏	24th October.
Sagittarius	Archer	♐	22nd November.
Capricornus	Goat	♑	22nd December.
Aquarius	Waterman	♒	20th January.
Pisces	Fishes	♓	19th February.

72. It appears therefore that the day of the spring equinox the sun enters Aries, that of the summer solstice, Cancer, that of the autumn equinox, Libra, and that of the winter solstice, Capricorn.

The points through which the sun passes at the solstices have therefore been called the TROPIC OF CANCER and the TROPIC OF CAPRICORN respectively.

73. It has been shown in our Tract on "Time," that the equinoctial points, and consequently all the signs of the zodiac, have a slow backward motion on the firmament at the rate of a degree in 72 years. They would therefore move back through 30°, or an entire sign, in 2160 years. Now it is known that in the time of an illustrious astronomer, Hipparchus, who flourished in Rhodes and Alexandria about 150 years before Christ, that is above 2000 years ago, the vernal equinoctial point was in the constellation of Aries, from which the first sign of the zodiac took its name, and consequently that all the other zodiacal constellations were at the same epoch in their proper signs. But in the interval of 2000 years, the equinoctial points having, as above stated, moved backwards through about 30°, they have severally retired from their proper constellations, which are now consequently that distance before them; so that the second sign of the zodiac is occupied by the constellation ARIES, which gave its name to the FIRST sign, the third by the constellation TAURUS, which gave its name to the SECOND sign, and so on.

Although the twelve divisions of the zodiac have thus deserted their proper constellations, they have nevertheless retained their names. It is therefore very necessary to know that there is a great difference between the SIGN ARIES and the CONSTELLATION ARIES. The former merely signifies the first 30° of the ecliptic or of the zodiac, counting from the place of the sun on the 21st of March. The other signifies a certain group of stars, through which at present the sun passes in the month of February; and a like observation will be applicable to the two senses attached to Taurus, Gemini, and the other zodiacal names.

74. The name ZODIAC is derived from the Greek word ζωδίον (*Zodion*), a little animal, the fancied figures of the constellations being generally animals.

75. The circle of the heavens called the Ecliptic, along which the sun holds its annual course, lies along the middle of the celestial zone of the zodiac, and within this zone the planets are generally confined. Most of them never depart from the path of the sun, even so far as the extreme limits of the zodiac. There are, however, a few of the smaller planets, called planetoids or asteroids, discovered by the labours of modern observers, which do depart beyond the limits of the zodiac to the extent of many degrees, and which are hence often called ultra-zodiacal planets.

The ECLIPTIC derives its name from the fact that eclipses, whether of the sun or moon, can never take place except when the moon is in or very near to the ecliptic. The moon, however, like the planets, never departs beyond the limits of the zodiac, her distance from the ecliptic never exceeding five degrees, that is about ten times her own apparent diameter.

76. The apparent daily and yearly motions of the sun on the heavens are not at all the only celestial phenomena which are foretold in the almanacks. The diurnal motions, such as the rising, southing, and setting, and the monthly changes, of the moon, to say nothing of eclipses and other phenomena, is one of the chief purposes of the almanack to describe with the most minute precision, a precision which never fails to correspond with the phenomena when they take place.

But, besides the moon, all good almanacks give the positions in which the more conspicuous of the planets are presented, so as to become objects of easy and common observation. Thus, by the aid of an almanack, any person properly informed of the import of the terms in which the appearances and motions are described, can easily identify them when they present themselves.

The better class of almanacks also indicate the position in which, at each season of the year, the more remarkable constellations are seen during the night.

77. To profit by the mass of interesting and useful information thus supplied, it is not at all necessary to be a practical astronomer, but it *is* necessary to understand the meaning of a few astronomical terms, which fortunately admit of very easy and simple explanation.

The heavens are as thickly strewed with stars by day as by night, but they are rendered invisible by the overpowering splendour of the sun. It is only in the absence of that luminary, therefore, that such objects can be seen. One of the most interesting classes of predictions given in the almanacks are those which indicate the positions of the most remarkable celestial objects relatively to that of the sun, from time to time, through the year.

78. When an object is so placed that it is on the meridian at noon, it is said to be in CONJUNCTION. It is then in the same quarter of the heavens with the sun, and rises and sets either exactly with or very little before or after the sun. Such an object, consequently, can never be visible, at least not with the naked eye, for in some cases it may be seen by the aid of a telescope.

79. When an object is so placed that it is on the meridian at midnight, it is said to be in OPPOSITION, for it is then in the quarter of the heavens directly opposed to the sun. It rises either exactly at or very little before or after sunset, and sets either exactly at or very little before or after sunrise. Such a position is therefore the most favourable one an object can have for being observed, since it is above the horizon during the night, and below it during the day.

80. When an object is separated from the sun by a quarter of the entire circuit of the heavens, it is said to be in QUADRATURE. If in that case it be to the *East* of the sun, it follows the sun, and will arrive at the meridian six hours later than the sun, that is, at 6 P.M. If it be to the *West* of the sun, it will precede the sun, and will pass the meridian six hours before the sun, that is at 6 A.M.

81. An object which is in east quadrature will therefore rise at or a little before or after noon, and will be on the meridian at or a little before or after sunset. Such an object, therefore, will be visible towards the west from sunset to midnight, at or near which it will set.

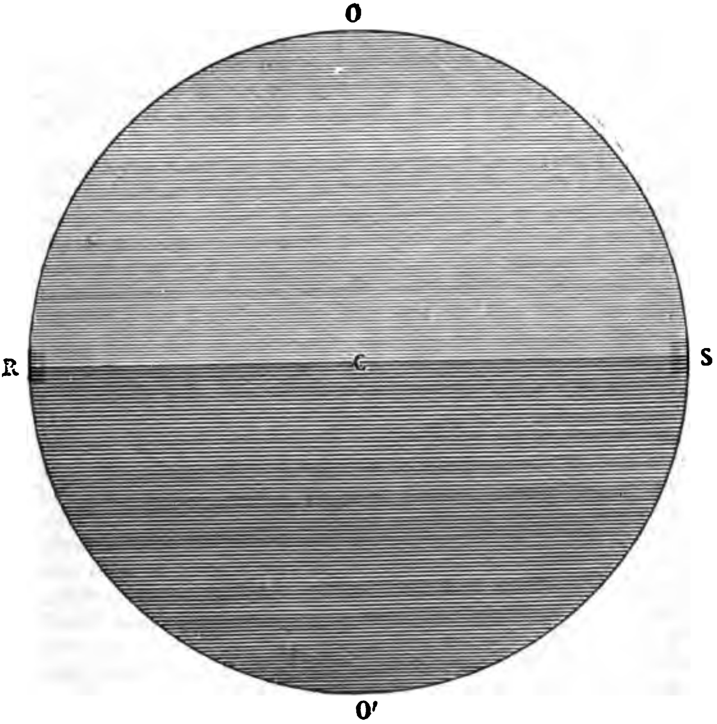
An object which is in west quadrature will, in like manner, rise at or a little before or after midnight, and will be on or near the meridian at sunrise. Such an object will therefore be seen towards the east from midnight to sunrise.

Thus, for example, when Venus, the most splendid of the planets, is removed from the sun towards the east, it is seen towards the west after sunset and continues to be visible until its own setting. It is then called the EVENING STAR. When it is removed to the west of the sun, it is seen towards the east before sunrise, and continues to be visible until it is lost in the blaze of the sun after sunrise. It is then called the MORNING STAR.

Venus as a morning star was called by the ancients LUCIFER (from the Latin words *ferre lucem*, to bring light), the Harbinger of Day. As an evening star it was called HESPERUS.

82. The preceding paragraphs will be more clearly understood by reference to fig 6. Let the observer be supposed to stand at C, with his face to the south. All objects in the heavens will then rise upon his left, R, and after ascending to the meridian, O, and descending from it, will set upon his right, S. They will pass

Fig. 6.



below the horizon, crossing the invisible half of the meridian at O′, and returning to R again to rise.

Thus, if we suppose the sun at O, which is its place at noon, an object in opposition will be at O′, and will therefore be invisible. At sunrise, the sun being at R, an object in opposition will be at or near S, and will therefore be setting; and at sunset, an object in opposition will be at or near R, and will therefore be rising. Between sunset and sunrise, the sun passing over S O′ R, an object in opposition will pass over R O S and will be at O at midnight, and will be visible in the heavens during the entire night.

An object in eastern quadrature will be at R when the sun is at O, at O when the sun is at S, at S when the sun is at O′, and at O′ when the sun is at R; so that from sunset to midnight it is visible in the west.

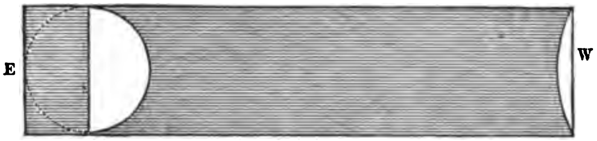
An object in western quadrature is at O when the sun is at R, at S when the sun is at O, at O′ when the sun is at S, and at R when the sun is at O′; so that from midnight to sunrise it is visible in the east.

83. It has been already shown (Museum, vol. iii. pp. 36, 37), that when the moon is in conjunction, being between the sun and the earth, and its enlightened hemisphere being presented to the sun, its dark side is turned towards the earth, so that even though it were favourably situated, it could not be seen. But from what has been just explained respecting an object in conjunction, it rises and sets with the sun, and therefore could not serve the purpose of illuminating the night even were it visible. The moon moves round the heavens from west to east at the rate of about 13° per day, while the sun moves in the same direction at the rate of about 1° per day. Therefore the moon advances eastward, departing from the sun at the rate of about 12° per day. On the 8th day, or about a week after conjunction, therefore, the moon will be 90° eastward of the sun; and, according to what was proved in vol. iii. pp. 36, 37, the moon will then be halved, the convex side of the semi-lune being presented westward towards the sun. Supposing as before, the observer to stand with his face to the south, the east will be on his left and the west on his right. In the case here supposed, therefore, the moon will appear halved as shown in fig. 7, at 90° east or to the left of the sun, and will follow the sun in its diurnal motion. The dark hemisphere of the moon indicated by the dotted semi-circle is turned eastward. The moon, therefore, in this case, moves with the straight edge of the semi-lune foremost.

This phase is called in the Almanack the FIRST QUARTER.

After conjunction, and before the moon arrives at this phase of the first quarter, it appears as a CRESCENT, the convex side of the crescent being turned westward, and towards the sun (fig. 8).

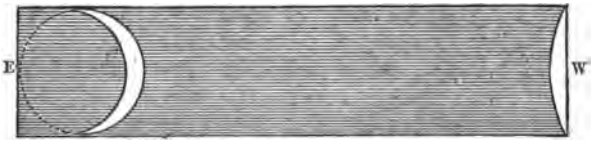
Fig. 7.



The crescent moves with its concave edge foremost. The unenlightened part of the moon is indicated by the dotted line in the figure.

In this phase the moon, not having yet arrived at the first quarter, is less than 90° east of the sun, and the less it is removed

Fig. 8.



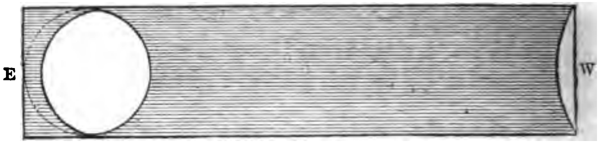
from the sun, the thinner is the crescent; and the more near it is to 90° from the sun, the more nearly does the crescent approximate to the half moon.

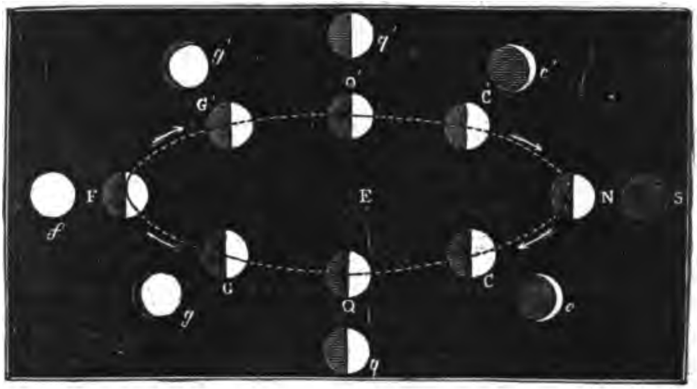
The moon being thus removed more or less to the east of the sun, or, what is the same, the sun being to the west of the moon, will set just before the moon; and the more the moon is removed from the sun, the longer will be the interval between sunset and moonset. After sunset the moon will therefore, soon after conjunction, be seen as a thin crescent in the western sky, and the farther it is removed eastward of the sun, the greater will be its altitude at sunset, the broader will be the crescent, and the larger will be the interval between sunset and moonset.

At length, when 7 days have elapsed, and the 8th day has commenced from the time of conjunction, the moon having advanced to 90° eastward of the sun, and being in quadrature, as in fig. 7, it will be on the meridian about sunset, and will not set until about midnight. Between sunset and midnight it will be seen to descend from the meridian to the western horizon.

84. Between the 8th and the 15th day from the time of conjunction, the moon, still advancing further and further eastward from the sun, will be seen eastward of the meridian at the time of sunset, and will then have the form represented in fig. 9, which is called the *gibbous* form, the edge presented westward and towards the sun being semi-circular, and that presented eastward and in the direction in which the moon is moving, being a semi-ellipse convex towards the east. This is, therefore, the form and appearance of the moon between the first quarter and the full moon, and the nearer it comes to the day of full moon—that is, to the fifteenth day from conjunction, the broader will be the gibbous disc, and the nearer will the outline approach to an exact circle.

Fig. 9.





THE LUNAR PHASES.

COMMON THINGS.

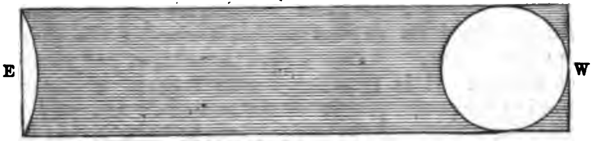
THE ALMANAC.

CHAPTER IV.

85. Full moon.—86. Last quarter.—87. Moon's age.—88. Rate of motion variable.—89. Causes thereof.—90. "May moon," "March moon," &c.—91. Confusion arising from this form of expression.—92. The epochs of chronology.—93. Anno Mundi.—94. Era of Nabonassar.—95. The Hegira.

85. On the 15th day after conjunction, the moon having receded from the sun at the rate of 12° per day, will have removed to 180°, that is, to the part of the heavens directly opposite to the place of the sun, and will be full as shown in fig. 10. According to what has been explained, the full moon, being in this position, will rise about the hour of sunset, will culminate at midnight, and

Fig. 10.

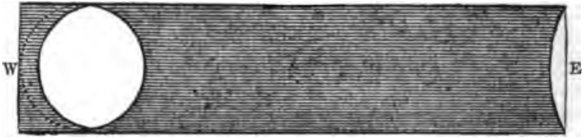


will set at sunrise. It is a remarkable character, therefore, of this arrangement that the position in which the illuminating power of the moon is greatest is precisely that in which it is present in the visible part of the firmament during the entire night.

86. After having been full, the moon still moving round the firmament in the same direction, begins to overtake the sun, and is now at less than 180° to the west of the sun; and as it advances from west to east, it approaches the sun at the rate of 12° per day; so that on the 22nd day it is only 90° west of the sun.

Between the 15th and 22nd days from conjunction, the distance of the moon west of the sun is less than 180°, but more than 90°, and according to what has been explained in vol. iii. pp. 36, 37, it is then gibbous, as shown in fig. 11, the semicircular edge being turned towards the sun, that is, towards the east, and the semi-elliptical edge towards the west. The moon now moves with the enlightened edge foremost, contrary to what took place before it was full. The unenlightened part, as before, is indicated in the figure by the dotted line.

Fig. 11.



Being more than 90° to the west of the sun, the moon must now be on the west of the meridian at sunrise, and must therefore have culminated before sunrise. In this position, therefore, the moon is seen during the greater part of the night, and the early morning. It is also faintly visible in the heavens after sunrise, and until it sets, the sun's light not being sufficient to overpower it altogether.

On the 22nd day, the moon is 90° west of the sun, and is halved (fig. 2, vol. iii. pp. 36, 37). This is called in the almanack the LAST QUARTER. The moon rises at midnight and culminates about sunrise. It is therefore visible between midnight and sunrise in the eastern quarter of the heavens. After sunrise it is still faintly visible in the western quarter until it sets, which it does about the hour of noon.

From the 22nd to the 30th day of the conjunction the moon moves constantly nearer to the sun, being now a crescent the concave side of which is turned towards the west, and the convex side towards the sun, as shown in fig. 13, the moon still moving with the convex side of the crescent foremost. The crescent becomes thinner and thinner as the moon approaches the sun.

Fig. 12.

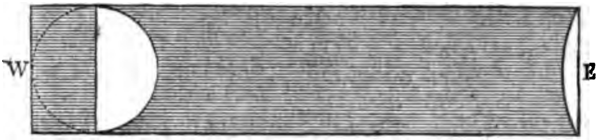
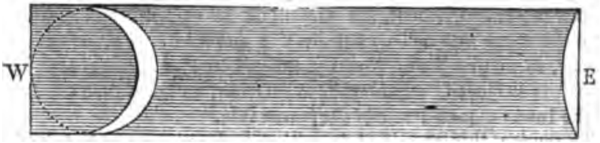
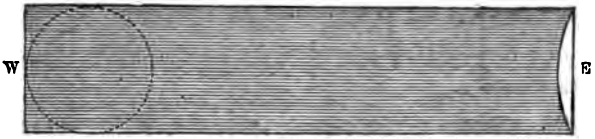


Fig. 13.



During this progressive change the moon being west of the sun, rises some time before it, and can be seen in the early morning, until it approaches so near the sun and until the crescent becomes so thin, that it is lost in the blaze of his splendour. The dark hemisphere is then presented to the earth, and the moon is invisible (fig. 14).

Fig. 14.



87. A column of the almanack is usually assigned to the "age of the moon." The sense in which this term is used, however, must not be confounded with that in which it is applied to the ecclesiastical moon in the rules for ascertaining the date of Easter. We are here dealing not with the fictitious but with the real moon; and the age in question is the interval which elapses between the moment of the last conjunction, and the moment at which the age professes to be assigned. This interval is usually given for the noon of each day, and is expressed in days and tenths of a day, but with still greater precision for the principal

phases, that is for conjunction, quadratures, and opposition, or as it is otherwise and more commonly expressed—for the new moon, the first quarter, the full moon, and the last quarter.

Thus, for example, when we find the moon's age on any proposed day given as 0·6, it is to be understood that at the civil or mean noon of that day, the time elapsed since the moment of conjunction was six-tenths of a day or 14 hours and 24 minutes. Again, if the age set down were 17·2, it is meant that at the noon of the day proposed an interval of 17 days and two-tenths of a day, that is 17 days 4 hours and 48 minutes, had elapsed since the moment of new moon.

88. By comparing together the dates of the successive phases of the moon as given in the almanack in each lunar month, and by comparing one with another the dates of the successive new moons, it will be found that the moon's motion during each lunar month is subject to considerable variation, and also that the length of the lunar month itself is very variable.

To render this manifest it will only be necessary to take from the almanack the dates of the phases during a lunar month, and the dates of the new moons during a year, and to compare them together.

Thus for example in the almanack for 1855 we find the following dates for the successive phases of the moon which was new on the 16th February.

		H.	M.	S.	
New Moon . . .	February 16, at	6	47	30	p.m.
First Quarter . . .	February 23, at	5	33	42	,,
Full Moon	March 3, at	10	8	0	,,
Last Quarter	March 11, at	1	59	18	,,
New Moon	March 18, at	4	45	12	a.m.

From which it follows that the intervals between the successive phases were—

	D.	H.	M.	S.
From New Moon to First Quarter . . .	6	22	46	12
From First Quarter to Full Moon . . .	8	4	34	18
From Full Moon to Last Quarter . . .	7	15	51	18
From Last Quarter to New Moon . . .	6	14	45	54
	29	9	57	42

Thus it appears that so far from the rate of the moon's apparent motion relatively to that of the sun being uniform through a lunar month, it is subject to so considerable a variation that while the first quarter is made in little more than 6 days 22¾ hours, the second is only completed in 8 days and 4½ hours.

If we compare the lengths of the successive lunar months we shall find a like variation. The following are the dates of twelve successive lunar months in 1855, and their lengths severally are given in the second column:—

1855.

NEW MOONS.				INTERVALS.			
	H.	M.	S.	D.	H.	M.	S.
Jan. 18	8	37	24 a.m.				
Feb. 16	6	47	30 p.m.	29	10	10	6
March 18	4	45	12 a.m.	29	9	57	42
April 16	3	4	30 p.m.	29	10	19	18
May 16	2	13	18 a.m.	29	11	8	48
June 14	2	28	54 p.m.	29	12	15	36
July 14	4	1	0 a.m.	29	13	32	6
Aug. 12	6	52	24 p.m.	29	14	51	24
Sept. 11	10	51	42 a.m.	29	15	59	18
Oct. 11	3	23	42 a.m.	29	16	32	0
Nov. 9	7	31	0 p.m.	29	16	7	18
Dec. 9	10	17	48 a.m.	29	14	46	48

Thus it appears that these eleven lunar months vary in length from $29^d\ 9^h\ 57^m\ 42^s$ to $29^d\ 16^h\ 32^m\ 0^s$, and if the comparison were carried further, a still greater variation would be found.

89. The causes of this great and apparently irregular variation in the motion of the moon are very numerous and complicated, as may be imagined when it is stated, that in order to deduce the moon's true place in the heavens at any proposed time, from its place as resulting from its mean or average motion, it is necessary to apply from thirty to forty corrections, each of which represents the effect of some disturbing force, the principal of which, however, are traceable to the varying action of the sun upon the moon.

90. It appears from the preceding table, that the day of new moon may fall indifferently upon any day of the calendar month. In common popular language, and more especially upon occasions on which certain influences are imputed (however erroneously) to the moon, that luminary is associated with the month, so that we hear of this and that effect of the "May moon," or the "March moon," and so on. Now, as neither the beginning nor the end of the age of the moon, nor even its length, has any necessary correspondence with the beginning or the end or the length of the month, it may be asked, by what condition the "May moon" is connected with May, or the "March moon" with March.

It might be imagined that the moon would take its name from the month in which it passes the greater part of its life. Such, nevertheless, is not the case. According to the most generally adopted custom, the moon takes its name from the month in which its age terminates. Thus, the May moon is that moon which ends in May, and the March moon, that which ends in March. All writers on chronology and the calendar agree in this, among whom may be cited the author of the well-known work entitled *l'Art de vérifier les Dates.*

91. Nevertheless, it must be admitted that this definition is attended with consequences which will seem rather absurd and inconsistent. Let us suppose, for example, that the moon happens to be new a little after the midnight which commences the 1st May. According to the definition, the moon which commenced its life on the 2nd April, and which finished it on the morning of the 1st May, must be called not the "April moon," but the "May moon."

But another consequence would in that case also follow, which shows in a striking manner the confusion which occasionally arises from this form of expression. In the case here supposed, the moon which was new soon after the midnight with which the 1st May commenced, would finish before the end of May, and would, therefore, according to the definition, be also called the "May moon." In fine, in such case, there would be two May moons, one whose entire age, except a few seconds, was passed in April, and the other, whose age began and ended in May.

It is easy to perceive that, the month of February in a common civil year having only 28 days, while the length of a lunar month always exceeds 29 days, it may happen that there will be no February moon. This will, in fact, occur if the moon be new on the afternoon of the 31st January.

Similar inconsistency and confusion would, however, equally ensue, if the moon took its name from the month in which it is new.

Independently of other causes of confusion arising from this custom of identifying the moon with the month in which it ends, there is the case in which the *same moon* might in one place take the name from one month, and in another place from the month preceding or following. Thus, for example, in the case of two places having a difference of longitude of 10 minutes, the hour at one place will be 10 minutes later than at the other. Now, let us suppose that the moon is new at 5 minutes before the midnight which terminates the last day of the month at one of the places. It will be new at 5 minutes after the midnight which terminates the month at the other place. Since the preceding moon ends its age in one of the places 5 minutes before the end of the month, and at the other place 5 minutes after the commencement of the next month, it will take its name at one place from the one month, and at the other from the other month. The moon which is the "May moon" of Paris may, therefore, be the "April moon" of London.

92. We shall conclude this brief exposition of the principal subjects included in the almanack, with some notice of the different epochs or eras which different nations have in different ages adopted as the zeros or starting points of their chronology.

93. It is evident that when any great event, political or religious, is adopted as the era, it would in general be necessary to count from it forwards and backwards, forwards for subsequent and backwards for preceding events. One era only would be exempt from this, and that is the era of the creation of the world, in which an event is dated ANNO MUNDI. Many profound researches have been accordingly made, to determine the date of this great standard of human chronology.

Unfortunately, however, the only authorities which could throw light upon the question, are involved in much obscurity, and give inconsistent results. The Hebrew, the Samaritan, and the Septuagint texts are apparently at variance on this question.

The following are the results of the researches of different chronologists as to the age of the world:—

According to Julius Africanus, the date is	5500	B.C.
According to the monk Panodorus	5493	,,
According to the Greek researches	5509	,,
Scaliger, by a comparison of different texts	3950	,,
Father Pezron	5873	,,
Jewish estimate	3761	,,
Archbishop Usher	4004	,,

The estimates of Jewish historians are, however, very various. Josephus gives it as 4163 B.C., others give it as 6524 B.C.

The estimate most commonly adopted by chronologists is that of Archbishop Usher.

The era of the Julian period has been already explained.

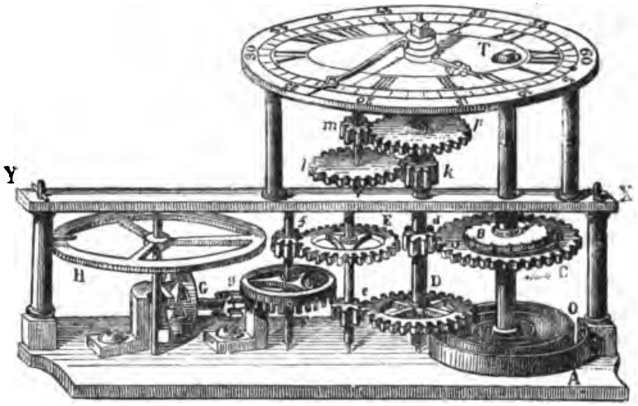
94. An era, called that of Nabonassar, has acquired a certain celebrity from the circumstance of its having been adopted as the point of departure in the calculations of several ancient astronomers, and more especially of Ptolemy.

The date of this era is 747 B.C.

It does not appear what circumstance determined the selection of this epoch, as there is no recorded event, social, political, or military, with which it is connected. It has been said that it is the date of the foundation of the kingdom of Babylon, out of the wreck of the Assyrian empire, after the death of Sardanapalus. It is also said that Nabonassar was the head of a new dynasty, and that he introduced the Egyptian year into Chaldea, but none of these statements have been satisfactorily proved.

95. The HEGIRA is the era of the Mohammedans. This word signifies FLIGHT, and refers to the flight of Mohammed from Mecca and his taking refuge at Medina, immediately after which his conquests commenced. The date of the Hegira is 622 A.D. But the Mohammedan year does not correspond with the Christian year, being determined by lunar months, and not by the seasons. Thus the year 1267 HEG. commenced on the 6th of November, 1850, and the year 1268 HEG. on the 26th of October, 1851, being 11 days less in length than the Christian year. The civil year of 365 days exceeds 12 mean lunar months of 29½ days by 11 days.

Fig. 17.



COMMON THINGS.

CLOCKS AND WATCHES.

◆

CHAPTER I.

1. General want of time measurers.—2. No natural measures for short intervals.—3. Approximative expedient by shadows.—4. Sun-dials.—5. Differently constructed for different places.—6. Earliest sun-dials.—7. Clepsydra, or water-clock.—8. Hour-glass.—9. Mercurial time-gauge.—10. Clocks—their chief parts.—11. Regulating power of the pendulum.—12. Uniform rate of vibration.—13. Analysis of a vibration.—14. Experimental verification of isochronism.—15. Moving power sustains the vibration.—16. Vibration not dependent on weight of pendulum.—17. Time of vibration varies with the length.—18. Analysis of motion of pendulous mass.—19. How the pendulum governs the hands.—20. Produces intermitting motion.—21. Pendulum's motion maintained by moving power.

1. After the supply of the absolute necessaries of physical existence—food, clothing, and lodging—one of the first wants of a society, emerging from barbarism, is the means of measuring and registering time. In civilised society, all contracts for labour, and for all kinds of service, are based upon time. Even in the cases of the highest public functionaries, and where the service rendered is purely social and intellectual, still it is regulated, limited, and compensated with relation to time. Time measurers

or chronometers were therefore among the earliest mechanical and physical inventions.

2. Although nature has supplied visible signs to measure and mark the larger chronometric units, such as days, months, and years, she has not furnished any corresponding measures of the lesser units of hours, minutes, and seconds. There are no visible marks on the firmament by passing from one to another of which the sun can note the hours, still less are there any signs for minutes or seconds. These subdivisions are therefore merely artificial and conventional, and to measure and mark them, artificial motions must be contrived.

3. Rough approximations were first made to the chief divisions of the day, by observing the apparent motion of the sun from rising to setting. Thus the direction of the meridian, or of the south, being once known, and marked by some fixed and visible object, the time of noon was known by observing when the sun had this direction. The hours before and after noon were roughly estimated by the position of the sun between noon and the times of its rising and setting. Greater precision was given to this method, by erecting a wand or gnomon, the shadow of which would fall upon a level surface, in a direction always opposite to that of the sun. Thus, after sunrise, the shadow would be inclined towards the west, the sun being then towards the east. From the moment of sunrise until noon, the shadow would move continually nearer and nearer to the direction of the north, and at noon it would have exactly that direction. From noon to sunset the shadow would be more and more inclined towards the east.

It is evident, however, that such a dial would not afford uniform indications at all seasons of the year, so that the hour-lines of the shadow determined in spring, for example, would not show the same hours in winter as in summer. Without much astronomical knowledge, it is easy to be convinced of this. At the equinoxes, the sun rises and sets at six o'clock, and at the east and west points precisely; and, therefore, at these seasons, the six o'clock hour-lines of such a dial would be for the morning due west, and for the evening due east. But on the first day of summer (21st June), the sun rises and sets at points of the horizon very much north of the east and west points, and at six o'clock in the forenoon and afternoon its bearing is north of the east and west points.

4. A dial so constructed at any given place would be useless as a time indicator. To render it useful, it would be necessary that the shadow of the style should fall in the same directions at the same hours at all seasons of the year. Now, to attain this object, the style must be not vertical, but must be directed to the celestial pole. It is easy to comprehend that in that case a plane

passing through the style and the sun would always be carried round the style with an uniform motion by the diurnal motion of the sun, and that at all seasons this plane would at the same hours have the same position.

It is for this reason that the gnomon of sun-dials is placed at such an inclination with the plate of the dial, that when the dial is properly set the gnomon will be directed to the north pole of the heavens, and being so placed, its shadow will fall upon the same lines of the dial at the same hours, whatever be the season of the year.

5. It is evident, therefore, that dials must be differently constructed for places which have different latitudes. We have shown in a former Tract* that the elevation of the celestial pole is equal to the latitude of the place, and consequently the inclination of the gnomon of a sun-dial must be also equal to the latitude of the place where the dial is intended to be set. It follows, therefore, that a dial constructed for London would not be suitable for York, Newcastle, or Edinburgh.

The position of the plate of the dial upon which the shadow of the gnomon is projected is quite unimportant. All that is really important is the direction of the gnomon, which must always be that of the celestial pole, whatever be the position of the plate of the dial. Thus the plate of the dial may be either horizontal, vertical, or oblique. Its position will depend upon the place where it is to be erected. If it be in an open space, as in a garden or field, having a clear exposure on all sides, it will be generally most convenient to make it horizontal; and, hence, in such cases, it is usual to fix it upon the top of a column of three or four feet high, so that it may be easily observed by a person of ordinary height standing near it. Sometimes it is convenient to place it upon the wall of a building, such as a church. A wall with a southern exposure is in that case the most convenient; but to indicate the hours of the early morning in the spring and summer, an eastern exposure would be required, and to indicate those of the late evening a western exposure would be necessary.

Where these vertical dials are erected, it is therefore frequently the practice to establish them at the same time on different walls of the same building.

Whatever be the position of the plate of the dial, the position of the hour-lines upon it is a matter of mere technical calculation, for which the formulæ and principles of spherical trigonometry are necessary, but which is not attended with any difficulty.

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* Vol. i. page 102.

It must, however, be observed, that generally the hour-lines are inclined to each other at unequal angles, as may be seen by inspecting any ordinary sun-dial. There is one, and one only, position which could be assigned to the plate of the dial, such that the hour-lines would make equal angles with each other. That position would be at right angles to the gnomon, and a dial so constructed would be suitable to any place, whatever be its latitude. All that would be necessary would be to set it so that the gnomon would be directed to the celestial pole. The sun, however, would shine upon the upper or north side of it during the spring and summer, and on the lower or south side during the autumn and winter. It would, therefore, be necessary that it should be marked on both sides with hour-lines, and that a gnomon should be fixed on both sides.

6. The name dial is derived from the Latin word *dies*, a day, and the invention and use of the instrument as a time indicator is very ancient. According to Herodotus, the invention came to Greece from Chaldæa. The first dial recorded in history is the hemisphere of Berosus, who is supposed to have lived 540 B.C.

7. The first attempts to measure time by motions artificially produced, consisted in arrangements, by which a fluid was let fall in a continuous stream through a small aperture in the pipe of a funnel, the time being measured by the quantity of the fluid discharged. The CLEPSYDRA, or water-clock, of the ancients, was constructed upon this principle. This and the sun-dial were the only instruments contrived or used by the ancients for the measurement of time.

Clepsydras were contrived by the Egyptians, and were in common use under the reign of the Ptolemys. In Rome, sun-dials were used in summer and clepsydras in winter. These instruments, though subject to very obvious defects, were, nevertheless, when skilfully used, susceptible of considerable accuracy, as may be easily conceived, when it is stated, that before the invention of clocks and watches, they were the only chronometric instruments used by astronomers. The chief sources of their irregularities were the unequal celerity with which the fluid is discharged, owing to its varying depth in the funnel and its change of temperature.

8. The common hour-glass comes under this class of chronometric instruments, but is the most imperfect of them. Nevertheless, for certain purposes, it is even now, advanced as we are in the application of science to the arts, still found the most convenient chronometer. The process of ascertaining a ship's rate of sailing or steaming by means of the log affords an example of its use. One man holds the reel from which the line runs off, while another holds the

sand-glass, and gives the signal when the sand has run out. The number of knots run off from the reel is then the number of miles per hour in the rate of the vessel. The intervals between the knots, the quantity of sand in the glass, and the aperture through which it falls, are so adapted to each other as to give this result.

9. Notwithstanding the great perfection to which the art of constructing chronometers has attained, an apparatus was not long since proposed by the late Captain Kater for the measurement of very small intervals of time, fractions of a second, for example, which is a modification of the clepsydra. A quantity of pure and clean mercury is poured into a funnel with a small aperture at its apex, so that a stream of the quicksilver shall fall through it. The flow is rendered uniform, by keeping the mercury in the funnel at a constant level. The apparatus is intended in scientific researches to note the exact duration of phenomena, and it is so managed, that the stream issuing from the funnel, is turned over a small receiver at the instant the phenomenon to be observed commences, and is turned away from it the instant the phenomenon ceases. The mercury discharged into the receiver is then accurately weighed, and the number of grains, and parts of a grain it contains, being divided by the number of grains which would be discharged in a second, the number of seconds, and the parts of a second, which elapsed during the continuance of the phenomenon is found.

10. For the purposes of civil life, as well as for the more precise objects of scientific research, all these contrivances have been superseded by clocks and watches, which are now so universal as to constitute a necessary article of furniture in the most humble dwellings, and a necessary appendage of the person in all civilised countries.

All varieties of this most useful mechanical contrivance include five essential parts.

1. A moving power.
2. An indicator, by whose uniform motion time is measured.
3. An accurately divided scale, upon which the indicator moves and by which its motion is measured.
4. Mechanism, by which the motion proceeding from the moving power is imparted to the indicator.
5. A regulator, which renders the motion imparted to the indicator uniform, and which fixes its celerity at the required rate.

Thus, for example, in a common clock, the moving power is the weight suspended by cords over a pulley fixed upon the axle of a wheel, to which the weight in descending imparts a motion of rotation. The indicator is the hand. The scale is the dial plate upon which the hours, minutes, and sometimes the seconds, are marked by equal divisions, over which the point of the hand moves. The mechanism is a train of wheelwork, so constructed that the rate of rotation of the last wheel upon the axle of which the hand is fixed, shall have a certain proportion to the rate of rotation of the first wheel, upon the axle of which the weight is suspended. And if, as is generally the case, there be two or three hands, then the wheel-work is so constructed, that while one of the hands makes one revolution, another shall make twelve revolutions, and the third shall make sixty revolutions during a single revolution of the latter, and therefore seven hundred and twenty during a single revolution of the former.

If no other appendage were provided, the weight would, in such an apparatus, descend with a continually increasing velocity, and would therefore impart to the hands a motion of rotation more and more rapid, which would not consequently serve as a measure of time. This defect is removed by the addition of a pendulum, combined with a wheel upon which it acts called the escapement. It is the property of the pendulum that its oscillations are necessarily made always in equal times, and its connection with the escapement-wheel is such, that one tooth of that wheel, and no more, is allowed to pass the upper part of the pendulum during each oscillation right and left. But this escapement-wheel itself forms part of the train of wheelwork by which the first wheel, moved by the descending weight, is connected with the wheels which move the hands, and consequently, by regulating and rendering uniform the motion of this escapement-wheel, the pendulum necessarily regulates and renders uniform the motion of the entire apparatus.

The instrument thus arranged, therefore, imparts an uniform motion of rotation to each of the hands, but this is not enough to render it a convenient time measurer. It is necessary that the motion of the hands should have some definite and simple relation to the natural and conventional division of time into days, hours, minutes, and seconds. For this purpose it is required not only that the hands should move uniformly, but that the first, or slowest of them, should make two complete revolutions in a day, or a single revolution in twelve hours; and, as a necessary consequence of this, that the second should make a single revolution in an hour, and the third in a minute.

11. From what has been stated, it will be apparent that the actual rate of motion imparted to the hands will be determined by the rate of oscillation of the pendulum. It has been shown that for each oscillation, right and left, of the pendulum, one tooth of the escapement-wheel passes, and if the escapement-wheel have

thirty teeth, and if the pendulum take one second to make a single swing, it will allow the escapement-wheel to make a complete revolution while it makes thirty swings from right to left, and thirty from left to right, that is, in sixty seconds, or one minute; so that, if the axis of the third hand were in this case fixed upon the axle of the escapement-wheel, that hand would make one complete revolution in a minute, and consequently the second would make one complete revolution in one hour, and the third in twelve hours. The required conditions would therefore be in this case fulfilled.

To render this explanation of the regulating property of the pendulum complete, it will be sufficient to show—1st, that the time of vibration must be always rigorously the same with the same pendulum; 2nd, that this time can be made shorter or longer by varying the length of the pendulum, so that a pendulum can always be constructed which will vibrate in one second, or in half a second, or, in short, in any desired time; and 3rd, that the connection of the pendulum with the escapement-wheel can be so constructed, that the motion of the latter shall be governed by the vibrations of the former, in the manner already described.

A pendulum consists of a heavy mass attached to a rod, the upper extremity of which rests upon a point of support in such a manner as to have as little friction as possible. Such an instrument will remain at rest when its centre of gravity is in the vertical line immediately under the point of suspension or support. But if the centre of gravity be drawn from this position on either side, and then disengaged, the instrument will swing horizontally from the one side to the other of the position in which it would remain at rest, the centre of gravity describing alternately a circular arc on the one side or the other of its position of rest. If there were neither friction nor atmospheric resistance, this motion of vibration or oscillation on either side of the position of equilibrium would continue for ever; but in consequence of the combined effects of these resistances, the distances to which the pendulum swings on the one side and on the other are continually diminished, until, after the lapse of an interval, more or less protracted, it comes to rest.

12. It is related that Galileo, when a youth, happening to walk through the aisles of a church in Pisa, observed a chandelier suspended from the roof, whose position had been accidentally disturbed, and which was consequently in a state of oscillation. The young philosopher, contemplating the motion, was struck with the fact, that although the range of its vibration was continually diminished as it approached a state of rest, the times of the vibration were sensibly equal, the motion becoming slower

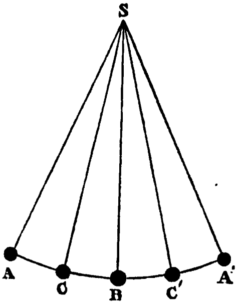
as the range of the oscillations became more limited. This led him to infer that property of the pendulum expressed by the word isochronism, in virtue of which the vibrations, whether in longer or shorter arcs, are performed in the same time.

Although, however, as we shall presently show, pendulums possess this property when the arcs of vibration are very small, they do not continue to manifest it when the range of vibration becomes more considerable.

13. To simplify the exposition of the important theory of the pendulum, it will be convenient, in the first instance, to consider it as composed of a heavy mass of small magnitude, suspended by a wire or a string, the weight of which may be neglected. Thus, let us suppose a small ball of lead suspended by a fine silken string, the length of which is incomparably greater than the diameter of the leaden ball. Such an arrangement is called the *simple pendulum*.

Let S, fig. 1, be the point of suspension; let S B be the fine silken thread by which the ball B is suspended, and the weight of which, in the present case, is neglected. Let B be the position of the ball when in the vertical under the point of suspension S. In that position the ball would remain at rest; but if we suppose the ball drawn aside to the position A, it will, if disengaged, fall down the arc A B, of which the centre is S, and the radius the length of the string. Arriving at B, it will have acquired a certain velocity, which, in virtue of its inertia, it will have a tendency to retain, and with this velocity it will commence to move through the arc B A′. Supposing neither the resistance of the atmosphere nor friction to act, the ball will rise through an arc B A′ equal to B A; but it will lose the velocity which it had acquired at B; for it is evident that it will take the same space, and the same time, to destroy the velocity which has been acquired, as to produce it. Thus, the velocity at B, being acquired in falling through the arc A B, will be destroyed in rising through the equal arc B A′.

Fig. 1.



Having arrived at A′, the ball, being brought to rest, will again fall from A′ to B, and at B will have again acquired the same velocity which it had obtained in falling from A to B, but in the contrary direction; and in the same manner it may be explained that this velocity will carry it from B to A. Having arrived at A, the ball, being again brought to rest, will fall once more from A to B, and so the motion will be continued alternately between A and A′.

The motion of the pendulum from A to A′, or from A′ to A, is called an *oscillation*, and its motion between either of those points and B is called a semi-oscillation, the motion from B to A or from B to A′ being called the ascending semi-oscillation, and the motion from A or A′ to B, the descending semi-oscillation.

The time which elapses during the motion of the ball between A and A′ is called the *time of one oscillation.*

It is evident, from what has been stated, that the time of moving from either of the extremities A, A′, of the arc of oscillation to the point B, is half the time of an oscillation.

If, instead of falling from the point A, the ball had fallen from the point C, intermediate between A and B, it would have then oscillated between C and C′; two points equally distant from B, and the arc of oscillation would have been C C′, more limited than A A′.

But in commencing its motion from C, the declivity of the arc down which it falls towards B would be evidently less than the declivity at A; consequently the force which would accelerate it, commencing its motion at C, would be less than that which would accelerate it, commencing its motion at A. The ball, therefore, commencing its motion at A, would be more rapidly accelerated than when it commences its motion at C.

The result of this is, that, although the arc A B may be twice as long as the arc C B, the *time* which the ball takes to fall from A to B will not be sensibly different from the time it takes to fall from C to B, provided that the arc of oscillation A B A′ is not considerable.

It was at first supposed, as we have just stated, that, whether the oscillations were longer or shorter, the times would be absolutely the same. Accurately speaking, however, this is not the case: but if the total extent of the oscillation A A′ do not exceed 5° or 6°, then the time of oscillation in it may be considered, practically, the same as in the lesser arcs.

14. This important principle may be easily experimentally verified. Let two small leaden balls be suspended from the same point of support, but one being in advance of the other, so that in oscillating the two balls shall not strike each other. This being done, let one of the balls be drawn from its point of rest through an angle less than 3°, and let it be disengaged. It will oscillate as described above. Let the other ball be now drawn from its point of rest through a much less angle, and let it be so

disengaged that it shall commence its oscillation at the same moment with the commencement of one of the oscillations of the other ball.

Let it, in short, be so managed, that when the one ball is at A, the other shall be at C; and that both shall commence their descending motion towards B at the same moment. It will be then found that their oscillations will be synchronous for a considerable length of time, that is to say, the balls will arrive at A′ and C′, respectively, at the same instant; and returning, will simultaneously arrive at A and C respectively.

If, in this case, the oscillation of the ball A were made through an arc, even as great as 10°, that is to say, 5° each side of the vertical, the oscillation of the ball C being made through an arc of 2°, it would be found that 10001 oscillations of the latter would be equal to 10000 oscillations of the former, so that the actual difference between their times of oscillation would not exceed the ten thousandth part of such time.

15. In the practical application of the pendulum, however, this departure from absolute isochronism, small as it is, becomes unimportant; for a power is always provided, by which the loss of motion which would be produced by friction and atmospheric resistance is repaired, and the magnitude of the oscillations is maintained uniform, as we shall presently show.

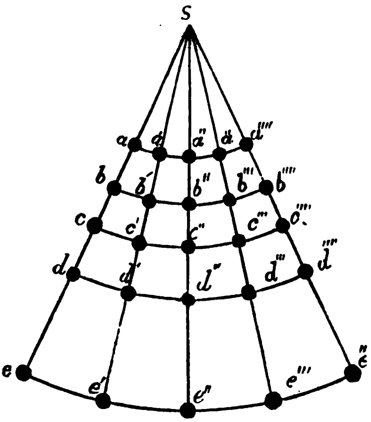
16. It might be expected that the time of oscillation of different pendulums would depend, more or less, upon the weight of the matter composing them, and that a heavy body would oscillate more rapidly than a lighter one. Both theory and experience, however, prove the result to be otherwise. The force of gravity which causes the pendulum to oscillate acts separately on all the particles composing its mass; and if the mass be doubled, the effect of this force upon it is also doubled; and, in short, in whatever proportion the mass of the pendulum be increased or diminished, the action of the force of gravity upon it will be increased or diminished in exactly the same proportion, and consequently the velocity imparted by gravity to the pendulous mass at each instant will be the same.

It is easy to verify this by experiment. Let different balls of small magnitude, of metal, ivory, and other materials, be suspended by light silken strings of the same length, and made to oscillate; their oscillations will be found to be equal.

17. If pendulums of different lengths have similar arcs of oscillation, the times of oscillation of those which are shorter will be less than the times of oscillation of those which are longer. Let *a*, *b*, *c*, *d*, and *e*, fig. 2, be five small leaden balls, suspended by light silken strings to the point of suspension S, and let all

of them be supposed to form pendulums, having the same angle of oscillation. The arc of oscillation of the ball *a* will be $a\,a''''$, that of *b* will be $b\,b''''$, that of *c*, $c\,c''''$, and so on. In commencing to fall from the points *a*, *b*, *c*, *d*, *e* towards the vertical line, these five balls are equally accelerated, inasmuch as the circular arcs down which they fall are all equally inclined at this point to the vertical line. The same will be true if we take them at any corresponding points, such as a', b', c', d', e'. It may therefore be concluded, that throughout the entire range of oscillation of each of these five pendulums, they will be impelled by equal accelerating forces.

Fig. 2



Now it is shown by the principles of mechanics, that when bodies are impelled by the same or equal accelerating forces, the spaces through which they move are proportional to the squares of the times of their motion; therefore it follows, that the lengths of these arcs of oscillation are proportional to the squares of the times. But the lengths of these arcs are evidently in the same proportion as the lengths of the pendulums, that is to say, the arc $a\,a''''$ is to $b\,b''''$ as S *a* is to S *b*, and the arc $b\,b''''$ is to $c\,c''''$ as S *b* is to S *c*, and so on.

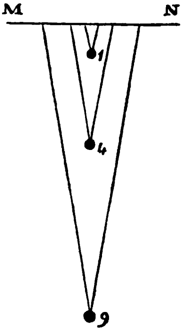
It follows, therefore, that the squares of the times of oscillation of pendulums are as their lengths, or, what is the same, the times of oscillation are as the square roots of their lengths. This principle is easily verified experimentally.

Let three small leaden balls be suspended vertically under each other by means of loops of silken thread, as represented in fig. 3, and in such a manner that they can all oscillate in the same plane at right angles to the plane of the diagram, the suspending loops not interfering with each other.

Let the loops be so adjusted that the distance of the ball 1 below the line M N shall be 1 foot, the distance of the ball 4, 4 feet, and the distance of the ball 9, 9 feet.

Let the ball 9 be put in a state of oscillation through small arcs, and let the ball 4 be then drawn from its vertical position, and disengaged so as to commence one of its oscillations with an oscillation of the ball 9; and in the same manner let the ball 1 be started simultaneously with one of the oscillations of the ball 9.

Fig 3



It will be found that two oscillations of the one-foot pendulum are made in exactly the same time as a single oscillation of the four-foot pendulum; consequently, the time of each oscillation of the latter will be double that of the former, while its length is fourfold that of the former.

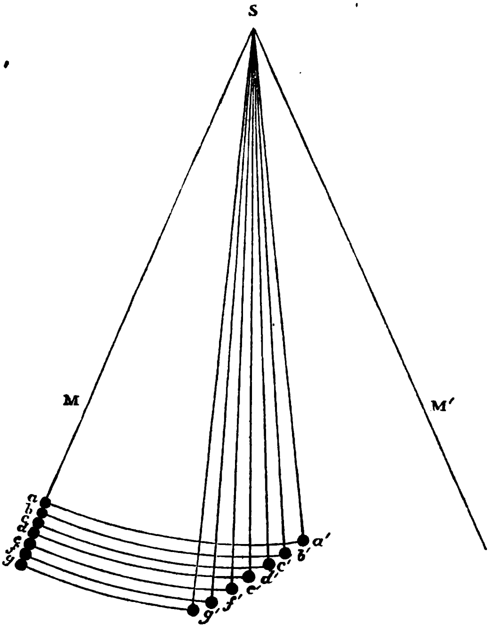
In the same manner, while the one-foot pendulum makes three oscillations, the nine-foot pendulum will make one, and, consequently, the time of oscillation of the latter will be three times that of the former, while its length is nine times that of the former.

By this principle, the length of a pendulum which would oscillate in any proposed time, or the time of oscillation of a pendulum of any proposed length can be ascertained, provided we know the length of a pendulum which oscillates in any given time.

18. We have hitherto supposed that the pendulous body is a heavy mass of indefinitely small magnitude, suspended by a wire or string having no weight. These are conditions which cannot be fulfilled in practice. Every real pendulous body has a definite magnitude, its component parts being at different distances from the point of suspension; the rod which sustains it is of considerable weight, and all the points of this rod, as well as those of the pendulous mass itself, are at different distances from the point of suspension. In estimating, therefore, the effect of pendulums, it is necessary to take into account this circumstance.

Let us suppose *a*, *b*, *c*, *d*, *e*, *f*, *g* (fig. 4), to be as many small heavy balls connected by independent strings, the weight of which may be neglected, with a point of suspension S, and let these seven balls be supposed to vibrate between the positions S M and S M′. Now if these balls were totally independent of each other, and connected with the point of suspension by independent strings, they would all vibrate in different times, those which are nearer the point S vibrating more rapidly than those which are more distant from it. If, therefore, they be all disengaged at the same moment from the line S M, those which are nearest to S will get the start of those which are more distant, and at any intermediate position between the extremes of their vibration they will assume the positions *a'*, *b'*, *c'*, *d'*, *e'*, *f'*, *g'*. That which is nearest to the point B, and which is the shortest pendulum, will be foremost, since it has the most rapid vibration. The next in length, *b'*, will follow it, and so on; the most remote from S being the longest pendulum, *g'* being the last in order.

Fig. 4



Now if, instead of supposing these seven balls to be suspended by independent strings, we imagine them to be fixed upon the same wire, so as to be rendered incapable of having any independent motion, and compelled to keep in the same straight line; then it is evident, that while the whole series vibrates with a common motion, those which are nearest to the point of suspension will have a tendency to accelerate the motion of those which are more distant, while those which are more distant will have a tendency to retard the motion of those which are nearer.

These effects will produce a mutual compensation; *b* and *c* will vibrate slower than they would if they were moving freely, while *e* and *f* will evidently move more rapidly than if they were moving freely. Among the series, there will be found a certain point, which will separate those which are moving slower than their natural rate, from those which are moving faster than their natural rate; and a ball placed at this point would vibrate exactly as it would do if no other balls were placed either above or below it. Such a ball would, as it were, be the centre which would divide those which are accelerated from those which are retarded.

Such a point has, therefore, been denominated the *centre of oscillation.*

It is evident then, that a pendulous mass, of magnitude more or less considerable, will vibrate in the same time as it would do if the entire mass were concentrated at its centre of oscillation, and formed there a material point of insensible magnitude.

By the length of a pendulum, no matter what be its form, is always to be understood the distance of its centre of oscillation from its point of suspension.

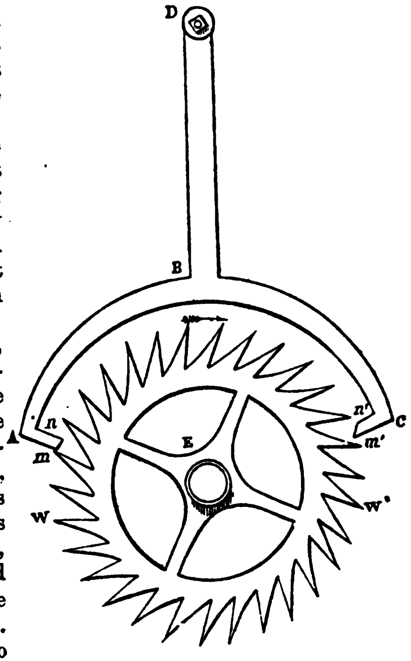
It will be seen from what has been explained above, that by varying the distance of the centre of gravity of the pendulum from the point of suspension, the centre of oscillation, and therefore the virtual length of the pendulum, and consequently its time of vibration, may be varied. The instrument may therefore be so adjusted, that the time of its vibration shall be a second, or any fraction of a second, that may be desired.

19. Supposing, then, the pendulum to be so adjusted, that it shall make its vibrations at any required rate, one per second for example, let us see how the motion of the indicating hands is governed by such vibrations.

Upon the axis on which the pendulum oscillates is fixed a piece of metal in the form of an anchor, such as D B A C (fig. 5), so that this piece shall swing alternately right and left with the pendulum. Two short pieces, *m* and *m'*, called pallets, project inwards at right angles to it from its extremities A and C.

The form and dimensions of the anchor A B C are accommodated to those of the escapement-wheel, W W', which is part of the clockwork, and which, in common with the other wheels forming the train, is moved in the direction indicated by the arrow by the weight or main-spring. When the anchor swings to the right the pallet *m* enters between two teeth of the wheel, the lower of which coming against it, the motion of the wheel is for the moment arrested. When it swings to the left, the pallet *m* is withdrawn from between the teeth, and the wheel is allowed to move, but only for a moment, for the other pallet *m'* enters between two teeth at the other side, the upper of which coming against it the motion of the wheel is again arrested.

Fig 5



The wheel, therefore, is thus made to revolve on its axis, E, not with a continuous motion, as would be the case if it were impelled by the weight or mainspring, without the interference of any obstacle, but with an intermitting motion. It moves by starts, being stopped alternately by one pallet or the other coming in the way of its teeth.

When the pendulum, and therefore the anchor, is at the extreme right of its play, the pallet, *m*, having entered between two teeth, a tooth rests against its lower side, the wheel is arrested, and the pallet, *m′*, is quite disengaged from, and clear of, the teeth of the wheel. When in swinging to the left the arm D B becomes vertical, the tooth of the wheel on the left has just *escaped* from the pallet, *m*, and the wheel being liberated, has just commenced to be moved by the force of the weight or mainspring. But at the same moment the pallet, *m′*, enters between the teeth of the wheel on the right, and when the anchor has arrived at the extreme left of its play, the tooth of the wheel, which is above the pallet, *m′*, will have fallen upon it, so that the motion will again be arrested.

Thus it appears, that during the first half of the swing from right to left, the motion of the wheel is arrested by the pallet, *m*, and during the remaining half of the swing the wheel moves, but is arrested the moment the swing is completed.

In like manner it may be shown, that during the first half of the swing from left to right, the motion of the wheel is arrested by the pallet, *m′*, that it is liberated and moves during the latter half swing, and is again arrested when the swing is completed.

20. The motion which is imparted to the hands upon the dial necessarily corresponds with this intermitting motion of the escapement-wheel. If the clock be provided with a seconds-hand, the circumference of the dial being divided into sixty equal parts by dots, the point of the seconds-hand moves from dot to dot during the second half of each swing of the pendulum, having rested upon the dot during the first half swing.

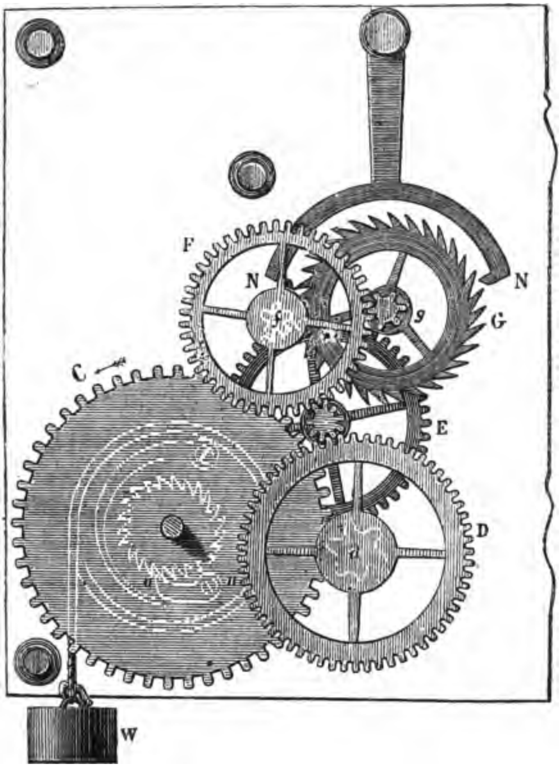
The whole train of wheel-work being affected with the same intermitting motion, the minute and hour hands must move, like the second hand, by intervals, being alternately moved and stopped for half a second. This intermission, however, is not so observable in them as in the seconds-hand, owing to their comparatively slow motion. Thus, the minute-hand moving sixty times slower than the seconds-hand, moves during each half swing of the pendulum through only the sixtieth part of the space between the dots, and the hour-hand moving twelve times slower than the minute-hand moves in each half swing of the pendulum, through the 360th part of the space between the dots. It is easy, therefore, to comprehend how changes of position so minute are not perceptible.

21. If the pendulum vibrated upon its axis of suspension unconnected with the clockwork, the range of its oscillation would be gradually diminished by the combined effects of the friction upon its axis and the resistance of the air, and this range thus becoming less and less, the oscillation would at length cease altogether, and the pendulum would come to rest. Now this not being the case when the pendulum is in connection with the wheelwork, but on the contrary, its oscillations having always the same range, it is evident that it must receive from the escapement-wheel some force of lateral impulsion, by which the loss of force caused by friction and the resistance of the air is repaired.

It is easy to show how the effect is produced. It has been shown that during the first half of each swing, a tooth of the escapement-wheel rests upon one or other pallet of the anchor. The pallet re-acts upon it with a certain force, arresting the motion of the wheelwork, and receives from it a corresponding pressure. This pressure has a tendency to accelerate the motion of the pendulum, and this continues until the tooth slips off, and is liberated from the pallet. It is this force which repairs the loss of motion sustained by the pendulum by friction and atmospheric resistance.

Thus we see, that while on the one hand the pendulum regulates and equalises the motion imparted to the wheelwork by the weight or mainspring, its own range is equalised by the reaction of the weight or mainspring upon it.

Fig 18.



COMMON THINGS.

CLOCKS AND WATCHES.

CHAPTER II.

22. Action of pendulum on escapement wheel.—23. Rate of motion of hands produced by tooth and pinion work.—24. Method of making pinions. —25. Mutual action of toothed wheels.—26. Wheel and pinion.— 27. Bevelled and crown wheels.—28. Weight applied as a moving power.—29. Why hands not turned back when clock is wound up. —30. Mainspring.—31. Its power variable.—32. The fusee.—33.

Balance-wheel.—34. Its vibrations uniform.—35. General explanation of a watch.—36. Of a clock moved by a weight.—37. Method of regulating the rate.

22. If the action of the anchor of the pendulum upon the escapement-wheel be attentively considered, it will be perceived that one tooth only of the escapement passes the anchor for each double vibration made by the pendulum. Thus, if we suppose that when the pendulum is at the extreme left of its range, the right-hand pallet is between the teeth *m′* and *n′*, the tooth *n′* will escape from the pallet C when the pendulum, swinging from left to right, comes to the vertical position, which is the middle of its swing. While it rises to the extreme right of its range, the tooth *n′* advances to the place which *m′* previously occupied, and at the same time the tooth *m* advances to the place which *n* previously occupied; but, at the same time, the pallet A, carried to the right, enters between *m* and the succeeding tooth, and arrests the further progress of the wheel. When the pendulum then swings to the left, the wheel continues to be arrested until it arrives at the middle of its swing, when the tooth below *m* escapes from the pallet A, but at the same moment the pallet C enters below the tooth which is above *n′*, and receiving it at the end of the swing, stops the motion of the wheel. Thus it appears, that tooth after tooth, in regular succession, falls upon the pallet C upon the arrival of the pendulum at the extreme left of its play after each double oscillation.

If the pendulum be so constructed that it shall vibrate in a second, and that it be desired that the escapement-wheel shall make a complete revolution in a minute, that is during sixty vibrations of the pendulum, the wheel must have thirty teeth. In that case, one tooth passing the anchor during each double oscillation from right to left, and back from left to right, thirty teeth, that is the whole circumference of the wheel, will pass the anchor in thirty double oscillations, or in sixty single swings of the pendulum, the time of each swing being one second.

23. The manner in which different rates of revolution can be imparted to the different hands of a clock or watch, by tooth and pinion work, is easily rendered intelligible.

The wheels commonly used in watch and clockwork are formed from thin sheets of metal, usually brass, which are cut into circular plates of suitable magnitude, upon the edges of which the teeth are formed. The edges of the wheels thus serrated are brought together, the teeth of each being inserted between those of the other, so that if one be made to revolve upon its axle, its teeth pressing upon those of the other, will impart a motion of revolution to the other.

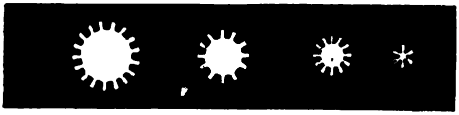
When a large wheel works in the teeth of a much smaller one, which is a very frequent case in all species of wheelwork, the smaller wheel is called for distinction a PINION, and its teeth are called LEAVES.

24. The method of manufacturing the pinions and smaller wheels used in watch and clockwork is very ingenious. A rod of wire, the diameter of which a little exceeds that of the wheel or pinion to be made, is drawn through an aperture cut in a steel plate, having the exact form and magnitude of the wheel or pinion to be formed. After being forced through this aperture by the ordinary process of wire-drawing, it is converted into a *fluted* wire, the ridges of the fluting corresponding exactly in form and magnitude to the edge of the aperture, and therefore to the teeth or leaves of the pinion or wheel.

This fluted wire, called *pinion wire*, is then cut by a cutter, adapted to the purpose, into thin slices, at right angles to its length. Each slice is a perfect wheel, or pinion; and it is evident that all of them must be absolutely identical in form and magnitude.

Such a wire-drawing plate, with apertures of different forms and sizes, is represented in fig. 6.

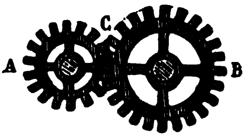
Fig. 6.



25. Two wheels of unequal magnitude, working one in the other, are represented in fig. 7. It will be easily perceived, that in this case their motions must be in contrary directions. Thus, if the wheel A move in the direction of the hand of a watch, the wheel B must move in the contrary direction.

Also, the rate at which they revolve on their axles will be in the inverse proportion of the number of their teeth. Thus, if the wheel B have fifty teeth, while the wheel A has only ten, it is evident that one revolution of B must be accompanied by five revolutions of A, since an equal number of teeth of each wheel must necessarily pass the point of contact C in the same time.

Fig. 7.



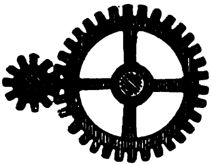
Now, in clock and watchwork, one of the objects to be attained is to cause certain wheels to revolve in a given numerical proportion to others. Thus, that upon the axis of which the seconds hand is fixed must make sixty revolutions, while that upon which the minute hand is fixed makes one. This would, therefore, be accomplished if the two wheels worked one in the other, the one having ten teeth and the other six hundred. But it is not necessary or convenient that the two wheels should thus be immediately in connection. Two or more wheels or pinions may be interposed between them, so that their relative velocities of rotation may result from the combined relations of the numbers of teeth or leaves in all the intermediate wheels and pinions.

26. A wheel working in a pinion is represented in fig. 8. When a very slow motion of rotation is to be converted into one many times faster, or *vice versâ*, this expedient is usually adopted.

A wheel and pinion are often fixed upon the same axis at more or less distance asunder. The pinion in this case may drive or be driven by a smaller wheel at a distance from the first, which is often convenient in clockwork and other machinery.

Thus, in fig. 17, the wheel C drives the pinion *d* which is fixed upon the axle of D, and drives it. The wheel D drives the pinion *e*, which drives the wheel E on the same axle, and the wheel E drives the pinion *f*, which drives the wheel F, and so on. In this way combinations of wheels and pinions may be arranged so as to modify in any desired manner the rate of rotation, and to transfer the rotation from axle to axle according to any proposed conditions.

Fig. 8.



27. In all these cases the axles round which the motion of rotation is produced are parallel one to another. In many cases, as well in clockwork as in other machinery, it is required to produce a motion of rotation round an axis at right angles to that upon which the motion already obtained is produced.

Fig. 9.

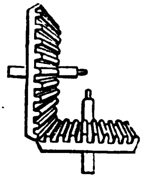
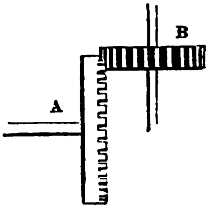


Fig. 10.



This is very simply and beautifully effected by either of two expedients, one of which is called BEVELLED, and the other CROWN wheels.

The manner in which the object is attained by bevelled wheels will be evident by inspecting fig. 9. The teeth in this case are formed upon a surface inclined to the axis at an angle of 45°, and the two axles make with each other consequently an angle of 90°.

In the crown wheel A, fig. 10, the teeth are raised upon the edge parallel to the axis, and work in the teeth or leaves of a wheel or pinion B, whose axle is at right angles to that of A.

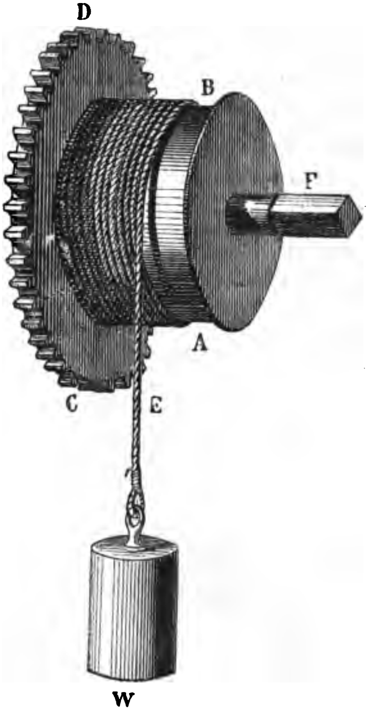
In clockwork, the crown wheel is the expedient used for this purpose, bevelled wheels being generally preferred in larger and heavier applications of wheelwork.

28. It has been already stated that the moving power applied to clock or watchwork is either a weight or a mainspring.

If a weight be the moving power, it is suspended to a cord which is coiled upon a drum fixed upon an horizontal axis, the first wheel of the train which gives motion to the hands being fixed on the same axis, so that it shall turn when the drum turns.

Such an arrangement is represented in fig. 11, where A B is the drum, C D the wheel attached to it and moved by it, W the weight which is the moving power suspended to the cord E, which is coiled upon the drum A B. The end, F, of the axis of the drum projecting beyond it, is made square, so as to receive a key made to fit it, by which it is turned, so as to coil the cord upon the axis, when it has been uncoiled by the descending motion of the weight.

Fig. 11.*



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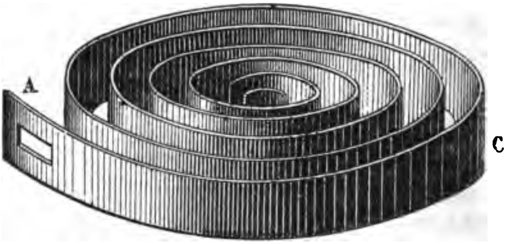
* This, and most of the succeeding diagrams have been copied from the excellent work "Cours Elémentaire de Mécanique," par Charles Delaunay —Victor Masson—Paris, 1854, with the permission of the author and publisher.

The direction in which the wheel C D is turned by the force of the descending weight is indicated by the arrow, and in that direction it will continue to turn so long as the weight acts upon the coil of the cord upon the drum. But so soon as the cord, by the continued descent of the weight, shall have been discharged from the drum, the rotation imparted to C D must cease. It is then that the key must be applied to the square end, F, of the axis of the drum, and turned continually in the direction contrary to that in which the weight would turn the drum in descending.

29. It will no doubt be perceived by the attentive reader, that, in this case, the hands of the clock would be always turned backwards while the clock is being wound up, unless some special provision were made against such an effect; for it is evident, that if the wheel C D, when turned by the descent of the weight W, in the direction of the arrow, give a progressive motion to the hands, the motion imparted to C D, by the ascent of the weight W, while the clock is being wound up, must necessarily impart to the hands a motion in the contrary direction, that is a backward motion.

In all clocks this is prevented by an expedient called a ratchet wheel and catch, the one being attached to the barrel A B, and the other to the face of the wheel C D, the effect of which is to allow the barrel A B, to be turned while the clock is being wound up in the direction contrary to that indicated by the arrow without turning the wheel C D; but when the barrel A B is turned by the descent of the weight W, in the direction of the arrow, the catch acting in the teeth of the ratchet-wheel, the motion of A B is imparted by the action of the catch on the ratchet-wheel to the wheel C D, and by it to the hands.

Fig. 12.



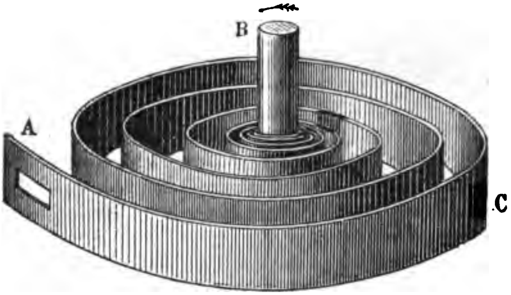
The form and mode of application of the ratchet-wheel will be presently more clearly explained.

30. The moving power of a weight can only be applied to time-

pieces where the space necessary for the play of the weight in its descent and ascent can be conveniently obtained. This condition is obviously incompatible with the circumstances attending pocket-watches, all portable and moveable timepieces, chimney, table, and console clocks, and in general all timepieces constructed on a small scale.

The moving power applied to these universally is a mainspring, which is a ribbon of highly tempered steel bent into a spiral form, as represented in fig. 12. At one end, A, an eye is provided, by which that extremity may be attached either to a fixed point or to the side of the barrel to which the spring is intended to impart motion. In the centre of the spiral an arbor, or axle, is introduced, to which the inner extremity of the spring is attached. Supposing the extremity A to be attached to a fixed point, let the arbor B (fig. 13), be turned in the direction indicated by the arrow. The spring will then be coiled closer and closer round the arbor A B, while its exterior coils will be separated one from another by wider and wider spaces.

Fig. 13.



After the spring has been thus coiled up by turning the arbor, it will have a tendency to uncoil itself and recover its former state, and if the arbor B be abandoned to its action and be free to revolve, it will receive from the reaction of the spring a motion of revolution contrary in direction to that which was given to the arbor in coiling up the spring, and such motion would be imparted to a wheel fixed upon the axle, and might from it be transmitted to the hands in the same manner as if the arbor-wheel received its motion from the power of a weight.

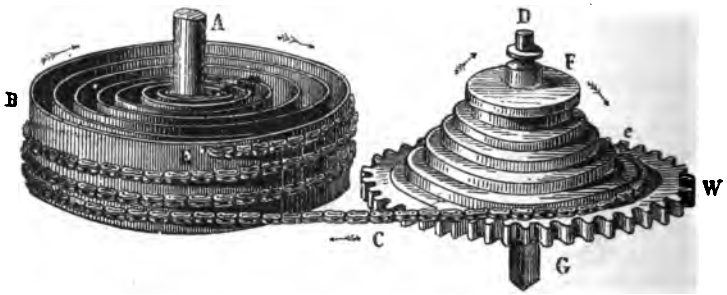
31. But between such a moving force and that of a weight there is an obvious difference. The tension of the cord by which the weight is suspended, and consequently its effect in giving revolution to the barrel upon which the cord is coiled, is always

the same until the clock altogether goes down. The moving force of the spring, on the contrary, is subject to a continual decrease of intensity. At first, when completely coiled up, its intensity is greatest, but as it turns the arbor B it becomes gradually relaxed, and its intensity is continually less and less. It exerts, therefore, a continually decreasing power upon the wheel fixed upon the arbor, and therefore upon the hands to which the motion is transmitted.

32. As a varying power would be incompatible with that uniformity and regularity which are the most essential and characteristic conditions of all forms of clockwork, such a spring would be quite unsuitable if some expedient were not found by which its variation could be equalised.

This has been accordingly accomplished, by a very beautiful mechanical contrivance, consisting of the combination of a flexible chain and a conical barrel arranged to receive its coils, called a FUSEE.

Fig. 14.



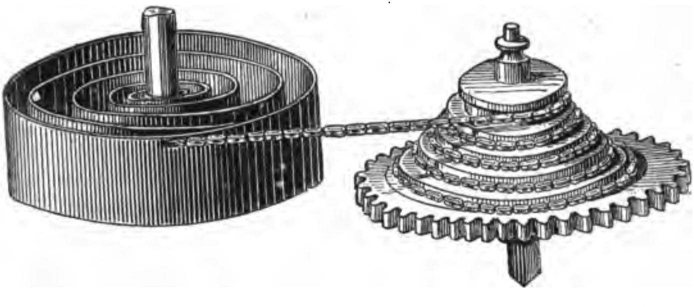
This arrangement is represented in fig. 14. The mainspring is attached by its inner extremity to the fixed arbor A, and by its outside end at E, to a barrel B, which is capable of being turned round the fixed axis A. A jointed chain is attached by one extremity to the barrel at E, and being coiled several times round it, is extended in the direction C, to the lowest groove of the fusee E, to which its other end, *e*, is attached. This fusee is a conical-shaped barrel, upon which a spiral groove is formed, continued from the base to the summit to receive the chain. The base is a toothed wheel, by which the motion imparted by the mainspring and chain to the fusee is transmitted to the hands through the wheelwork. The fusee is fixed upon an arbor, D G, the lower end of which, projecting outside the case containing the works, is formed square to receive a key made to fit it by which the clock or watch is wound up.

The action of the spring transmitted by the barrel to the chain, and by the chain to the fusee, has a tendency to impart to the fusee a motion of rotation in the direction of the arrows. The fusee is connected with the wheel, W, by means of a ratchet-wheel and catch similar to that described in the case in which the moving power is a weight, by means of which the fusee F imparts rotation to the wheel when it turns in the direction of the arrows, but does not move it when turned in the opposite direction.

These arrangements being understood, let us suppose the key applied upon the square-end G of the arbor D G of the fusee, and let it be turned round in the direction contrary to that indicated by the arrows. The fusee will then be turned, but will not carry the wheel W with it; the chain C will give to the barrel B a motion of revolution contrary to the direction of the arrows, the chain will be gradually uncoiled from the barrel B, and will be coiled upon the spiral groove of the fusee, winding itself from groove to groove, ascending on the spiral until the entire length of the chain has been uncoiled from the barrel B, and coiled upon the fusee F, as represented in fig. 15.

During this process, the external extremity of the mainspring, attached to the barrel at E, is carried round with the barrel, while the internal extremity is fixed to the arbor A, which does not turn with the barrel. By this means the spring is more and more closely coiled round the arbor A, until the entire chain has been discharged from the barrel to the fusee, when the spring will be coiled into the form represented in fig. 15, and in this state the intensity of its force of recoil, and the consequent tension of the chain C, extended from the barrel B to the fusee E, is greatest.

Fig. 15.



The clock being thus wound up and left to the action of the spring, the tension of the chain C, directed from the fusee to the spiral, will make the fusee revolve in the direction indicated by the arrows. This tension at the commencement acts upon the highest and smallest groove of the fusee. As the chain is gradually discharged from the fusee to the barrel, the tension is gradually decreased by reason of the relaxation of the spring, and at the same time the chain acts upon a larger and larger groove of the fusee. In this way the tension of the chain is continually decreased, and the radius of the groove on which it acts is continually increased, until the entire action has passed from the fusee to the barrel, and the clock goes down.

Now the power of the chain to impart a motion of revolution to the fusee depends on two conditions; first the force of its tension, and secondly the leverage by which this tension acts upon the fusee. This leverage is in fact the semi-diameter of the groove, upon which the chain is coiled at the point where it passes from the fusee to the barrel. Without much mechanical knowledge it will be easy to perceive that it requires less force to turn a wheel or barrel if the force be applied at a great distance from the axle than if it be applied at a small distance from it. Upon this principle generalised, it follows that the power of the tension of the chain to impart revolution to the fusee is augmented in exactly the same proportion as the magnitude of the groove on which it acts is increased.

The form given to the fusee is such that as the chain is gradually discharged from it, the diameter of the groove on which it acts increases in exactly the same proportion as that in which the tension of the chain decreases. It follows, therefore, that the power of the chain upon the fusee gains exactly as much by the increase of its leverage as it loses by the decrease of its tension, and consequently it remains invariable.

Complete compensation is therefore obtained by this beautiful and simple expedient, and a variable force is thus made to produce an invariable effect. It may be useful to state that this is only a particular application of a mechanical principle of great generality. In all cases whatever, the varying energy of a moving power may be equalised by interposing between it and the object to be moved some mechanism, by which the leverage, whether simple or complex, through which its force is transmitted, shall vary in the exact inverse proportion of the variation of the power,—increasing as the intensity of the power is decreased, and decreasing as the intensity of the power is increased.

33. Whatever be the moving power, whether it be a weight or mainspring, it would, if not controlled and regulated, impart to the hands a motion more or less accelerated, and therefore unsuitable to the measurement of time, which requires a motion rigorously

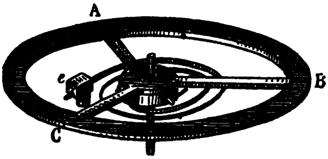
uniform. It is on that account that the moving power must be controlled and governed by some expedient, by which it shall be rendered uniform.

How the combination of a pendulum and escapement-wheel accomplishes this has been already explained. But this expedient requires that the timepiece to which it is applied shall be stationary; the slightest disturbance of its position would derange the mutual action of the pendulum and the escapement-wheel, and would either stop the movement, or permanently derange the mechanism. It is evident that a pendulum is not only inapplicable to all forms of pocket timepiece, but that it cannot even be used for marine purposes, the disturbances incidental to which would be quite incompatible with the regularity of its action.

The expedient which has been substituted for it with complete success in all such cases is the balance-wheel.

This is a wheel, like a small fly-wheel, having a heavy rim connected with the centre by three or more light arms, as shown at A B C, in fig. 16. Under, and parallel to it, is placed a spring resembling in form the mainspring, but much finer and lighter, and having much less force. This spring is formed of extremely fine and highly tempered steel wire, so fine that it is sometimes called a hair-spring. One extremity of this spring is attached to the axis of the balance wheel, and the other to any convenient fixed point in the watch. The spring is so constructed that when at rest it has a certain spiral form, to which it has a tendency to return when drawn from it on the one side or the other. If we suppose it, therefore, to be drawn aside from this position of rest and disengaged, it will return to it, but on arriving at it, having acquired by the elasticity a certain velocity, it will swing past it to the other side, to a distance nearly as far from its position of rest as that to which it had been originally drawn on the other side. It will then swing back, and will thus oscillate on the one side and the other of the position of rest, in the same manner exactly as that in which a pendulum swings on the one side or the other of the vertical line which is its position of rest.

Fig. 16.



34. The balance-wheel thus connected with a spiral spring, like the pendulum, is isochronous, that is, it performs all vibrations—long and short—in the same time. It will be recollected that this property of the pendulum depends on the fact that the

wider is the range of its vibrations the more intense is the force with which it descends to the vertical direction, and consequently wide vibrations are performed in as short a time as more contracted ones. Now the vibrations of the balance-wheel are subject to like conditions. The wider the range of its vibrations, the more intense is the force with which the recoil of this spring carries it back to its position of rest, and consequently it swings through these wide vibrations in the same time as through more contracted ones, in which the force of the spring is proportionally less intense.

The oscillation of the balance-wheel regulates the motion of watchwork in the same manner by means of an escapement-wheel, as that in which the pendulum regulates the motion of clockwork. The pallets and the escapement-wheel are, however, very variously formed in different watches.

35. Having thus explained generally the powers by which clocks and watches are moved and regulated, it now remains to show how the necessary motions are conveyed to the hands by suitable combinations of wheels and pinions.

In fig. 17 (p. 1), are represented the works of a common watch, moved by a mainspring A, and regulated by a balance-wheel H; the wheels and pinions, however, being changed in their relative positions, and the fusee being omitted, so as to show more visibly the connections and mutual dependency of the many parts. The external extremity of the mainspring is attached to the base, O, of a column of the frame. Its internal extremity is attached to the lower end of an axle, of which the square end, T, at the top enters a hole in the dial-plate into which the key is inserted when the watch is to be wound up. The ratchet-wheel B is fixed upon this axis so as to turn with it, but the other wheel C under the ratchet-wheel is not fixed upon it, the axis being free to turn in the hole in the centre of C, through which it passes. A catch *n o* is attached by a pin on which it plays to the face of the wheel C, and its point *o* is pressed against the teeth of the ratchet-wheel B, by a spring provided for that purpose. When the key is applied upon the end T, and turned in the direction in which the hands move, the ratchet-wheel is turned with it, and the point *o* of the catch—pressed constantly against the teeth while it turns—falls from tooth to tooth with an audible click, and thus produces the peculiar sound, with which every ear is familiar, while the watch is being wound up. During this process the wheel C does not turn with the axle, which only passes through the hole in its centre without being fixed upon it, but the mainspring, A, being attached to the axle is coiled more and more closely round it, and re-acts against the fixed point O with greater and greater force.

If the fusee, which is omitted in this figure, were introduced, it would occupy the place of the spring, and would be turned by the axle imparting a like revolution to the axis of the spring by means of the chain.

When the watch is wound up, the re-action of the spring, rendered uniform in its force by the fusee, imparts a motion of revolution to the ratchet-wheel B, in the direction of the arrow. By this motion the tooth of the ratchet-wheel in which the point *o* of the catch is engaged, presses against the catch so as to carry it round with it in the direction of the arrow; but the catch being attached to the face of the wheel C, at *n*, this wheel is carried round also in the same direction, and with a common motion.

The teeth of the wheel C act in those of the pinion *d*, which is fixed upon the axle *d* D. Upon the same axle is fixed the wheel D, so that the wheel D and the pinion *d* receive a common motion of revolution from the wheel C.

The wheel D, in precisely the same manner, imparts a common motion of revolution to the pinion *e*, and the wheel E; and the wheel E imparts a common motion of revolution to the pinion *f* and the wheel F.

This last wheel F is of the form called a crown-wheel, and acts upon the pinion *g*, imparting to it, and to the escapement wheel G, a common motion of revolution. This escapement-wheel is acted upon and controlled by the pallets or other contrivances attached to the axis of the balance-wheel H, so as to regulate its motion by the oscillations of that wheel in the same manner as the escapement-wheel of a clock is regulated by the anchor of the pendulum.

It may be asked why so long a series of wheels and pinions are interposed between the mainspring and the balance-wheel? and why the first pinion *d* may not act directly upon the escapement-wheel? The object attained by the multiplication of the wheels and pinions is to cause the mainspring, by acting through a small space, to produce a considerable number of revolutions of the escapement-wheel, for without that the spring would be speedily relaxed, and the watch would require more frequent winding up. Thus by the arrangement here shown, while the mainspring causes the wheel C to revolve once, it causes the pinion *d* and the wheel D to revolve as many times as the number of teeth in C is greater than the number in *d*. Thus if there are ten times as many teeth in C as in *d*, one revolution of C will produce ten of *d* and D. In like manner if D have ten times as many teeth as *e*, one revolution of D will produce ten of *e* and E, and so on. In this way it is evident that one revolution of the first wheel C, which is on the axis of the fusee, can be made by the mutual adaptation of the intermediate wheels and pinions, to impart as many revolutions as may be desired to the escapement-wheel G.

The wheels which govern the motion of the hands are those which appear in the figure between the watch face and the frame XY. The relative power of the mainspring aud balance-wheel must be so regulated that the wheel D shall make one revolution in an hour. The axis upon which this wheel is fixed passing through the centre of the dial, carries the minute hand, which therefore revolves with it, making one complete revolution on the dial in an hour.

Upon this axle of the minute hand is fixed a pinion *k*, which drives the wheel *l*, on the axle of which is fixed the pinion *m*, which drives a wheel *p*, through the centre of which the axle of the minute hand passes without being fixed upon it. Upon the axle of the minute hand a small tube is placed, within which it can turn. Upon this tube the hour hand, as well as the wheel *p*, is fixed. The pinion *k*, therefore, fixed upon the axis of the minute hand, imparts motion to the hour hand by the intervention of the wheel *l*, the pinion *m*, and the wheel *p*. Since the hour hand must make one revolution while the minute hand makes twelve, it is necessary that the relative numbers of the teeth of these intermediate wheels shall be such as to produce that relation between the motions of the hands. An unlimited variety of combinations would accomplish this, one of the most usual being the following:—

Pinion *k*	8 teeth.
Wheel *l*	24 ,,
Pinion *m*	8 ,,
Wheel *p*	32 ,,

By this arrangement *p* will make eight revolutions, while *m* and *l* make thirty-two; or, what is the same, *p* will make one revolution, while *m* and *l* make four. In like manner, *l* will make eight revolutions, while *k*, and therefore the minute hand, makes twenty-four; or, what is the same, *l* will make four revolutions, while *k* and the minute hand make twelve. It follows, therefore, that *p*, and therefore the hour hand, makes one revolution, while *k*, and therefore the minute hand, makes twelve, which is the necessary proportion.

In this case there is no seconds hand: but, if there were, its motion would be regulated in like manner by additional wheels and pinions.

36. The manner in which the moving power of a weight, and the regulating power of a pendulum are applied in a clock to

produce the motion of the hands, does not differ in any important respect from the arrangement explained above. Nevertheless, it may be satisfactory to show the details of the mechanism. The train of wheels connecting the weight with the anchor of the pendulum is shown in fig. 18 (p. 17).

A side view of the mechanism, showing the wheels which more immediately govern the motion of the hands, and also the pendulum, with its appendages, is given in fig. 19 (p. 33).

The weight W acts by a cord on a barrel, as already explained. This barrel and the ratchet-wheel, with its catch, are mounted upon the axis of the great wheel C, and are behind it, as represented in fig. 18, their form and position being shown by the white lines. The catch is attached to the wheel C by the screw *n*, and its point *o* acts on the teeth of the ratchet-wheel, which is attached to the barrel on which the rope is coiled. The spring which presses the catch against the teeth of the ratchet is also shown. When the clock is wound up by the key applied to the square end T (fig. 19) of the axis of the barrel, the barrel is turned in the direction opposite to that indicated by the arrows, and the catch falls from tooth to tooth of the ratchet-wheel, making the clicking noise which attends the process of winding up. When the clock has been wound up, the weight acting on the barrel presses the tooth of the ratchet-wheel against the catch, and thereby carries round with it the wheel C. This wheel transmits the motion to the escapement wheel G, fig. 17, through the series of wheels and pinions, *d*, D, *e*, E, *f*, F, and *g*, in the same manner exactly as has been already described (35); and the pendulum, by means of the anchor NN, regulates the motion in the manner described in 19.

The wheels which more immediately govern and regulate the motion of the hands are those which appear in fig. 19 in front of the plate XY.

The pendulum consists of a heavy disc of metal, seen edgeways at V in fig. 19, attached to the end of a metal rod, RR, represented broken, to bring it within the limits of the figure. This rod is suspended by various means, but often, as in the figure, by two elastic ribbons of steel, SS, which permit its swing right and left. It passes between the prongs of a fork U, by which a rod *rr* is terminated, so that this rod swings right and left with the pendulum. Upon the axis of this rod, and over the escapement wheel G, is fixed the anchor N of the escapement.

37. Whether the movement be regulated by a pendulum or a balance wheel, it is necessary to provide some means of adjustment by which the rate of vibration may be increased or diminished at pleasure within certain limits, for although in its original

construction the regulator may be made so as to oscillate *nearly* at the required rate, it cannot be made to do so *exactly*. Besides, even though it should vibrate exactly at the required rate, it will be subject, from time to time, to lose that degree of precision, and to vibrate too fast or too slowly from the operation of various disturbing causes.

It has been already shown, that the rate of vibration of the pendulum is rendered more or less rapid by transferring the centre of gravity nearer to, or farther from, the point of suspension. Upon this principle, therefore, the adjustment of the rate of vibration depends. The heavy disc V, fig. 19, is made to slide upon the rod RR, and can be moved upon it, upwards or downwards, by a fine screw attached to it, which works in a thread cut in the rod. In this manner the centre of gravity of the disc V may be transferred nearer to the suspension SS, so as to shorten the time of its vibrations, or removed farther from SS, so as to lengthen the time. If the clock is found to lose or go too slowly, it is screwed *up*, and if it gain or go too fast, it is screwed *down*.

In chimney and table time-pieces, the pendulum is regulated in a different manner. It is usually suspended upon a loop of silken thread, which can be drawn up or let down through a certain limited space, by means of a rod, upon which one end of the thread which forms the loop is coiled. This rod, passing through the dial-plate, has a square end, upon which a key can be applied, by turning which in the one direction or the other, the loop is drawn up or let down.

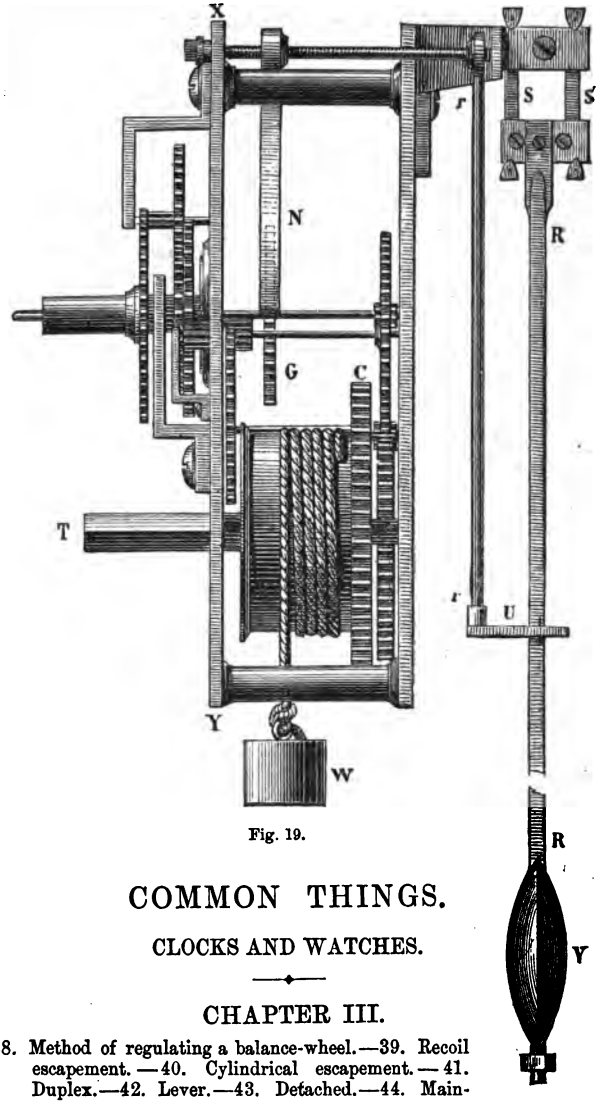


Fig. 19.

COMMON THINGS.

CLOCKS AND WATCHES.

◆

CHAPTER III.

38. Method of regulating a balance-wheel.—39. Recoil escapement.—40. Cylindrical escapement.—41. Duplex.—42. Lever.—43. Detached.—44. Maintaining power of a clock moved by a weight.—45. Of a watch moved by a mainspring.—46. Weight or mainspring and pendulum

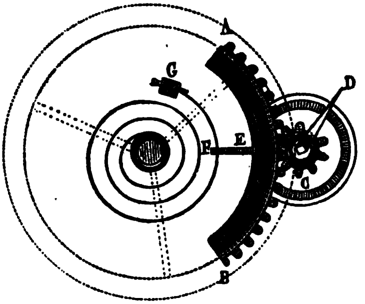
and balance-wheel variously combined.—47. Watches and chronometers.—48. Marine chronometers.—49. Stationary chronometers.—50. Striking apparatus.

38. The rate of oscillation of the balance-wheel cannot in the same manner be so easily regulated by modifying its form; but, on the other hand, while the force which moves the pendulum, being that of gravity, is beyond our control, that which moves the balance-wheel being the force of the spiral spring, is at our absolute disposition. It is accordingly by modifying this spring that we are enabled to regulate the time of oscillation of this regulator.

One of the most common expedients by which this is accomplished is represented in fig. 20.

Near the fixed point G, at the external extremity of the spiral, is placed a small bar E, near the end, F, of which is a notch, or hole, through which the wire of the spiral passes. This arrests the action of the spiral, so that the only part of it which oscillates is that which is included between F and its internal extremity. In a word, the point F is the virtual external extremity of the spiral. Now this point F can be moved in the one direction or the other, so as to increase or diminish the virtual length of the spiral at pleasure, by means of the toothed arc AB and the pinion C, which latter is turned by the index D. If the index D be turned to the left, the bar E, and the point F, is moved towards G, and the length of the spiral is increased. If it be turned to the right, the point F is moved from G, and the length of the spiral is diminished.

Fig 20.



In this manner the rate of vibration of the balance-wheel may be adjusted by varying at will the vertical length of the spiral-spring.

39. The precision of the movement of all forms of timepieces depends in a great degree on the mechanism of the escapement, and accordingly much mechanical skill and ingenuity have been directed to its improvement, and several varieties of form have been adopted and applied.

The recoil escapement, represented in fig. 17, consists of two pallets, which project from the axis of the balance-wheel at right angles with each other, one of which acts at the top, and the other at the bottom of the escapement-wheel G, the axis of which is horizontal and the wheel vertical. These pallets, as the balance-wheel oscillates, engage alternately in the teeth of the escapement-wheel exactly in the same manner as do the pallets of the anchor of the escapement attached to the pendulum already described. This form of escapement was long the only one used, and is still continued in the more ordinary sorts of watches.

It has, however, been superseded, in watches and chronometers where greater precision is required, by others of more improved construction.

40. In pocket watches, where great flatness is required, the cylindrical escapement is used, in which the axis of the balance-wheel, instead of having pallets attached to it, is formed into a semicylinder, having a sort of notch in it, as represented on an enlarged scale in fig. 21. The semicylinder *a b*, is cut away at *c*, through about half its height. The axis A B, fig. 22, of the escapement-wheel is vertical, and the teeth raised at right angles to its plane, and therefore parallel to its axis, have the peculiar form represented in the figure. As the balance-wheel oscillates on the one side and the other, the semicylinder upon its axis

Fig 21.

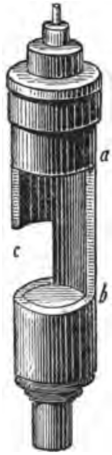
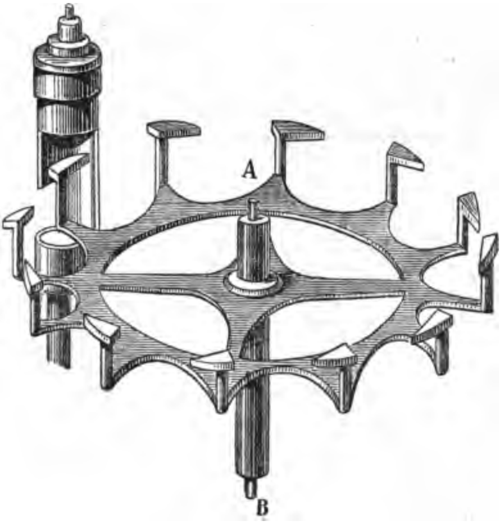
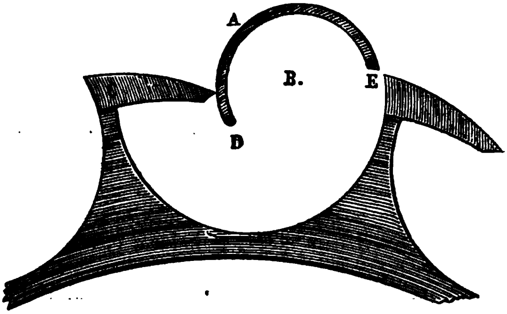


Fig. 22.



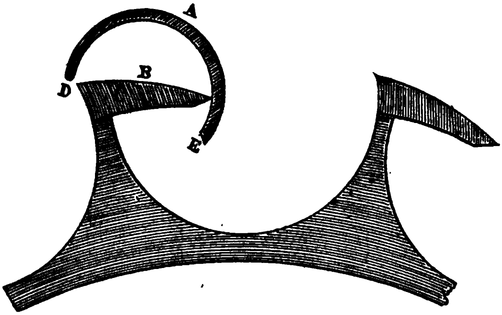
interposes itself alternately between the teeth of the escapement-wheel, stopping them and letting them escape in the usual way. The manner in which the action takes place will be more clearly understood by the figures 23 and 24, in which a view in plan upon an enlarged scale is given of the position of the semicylinder and the teeth of the escapement-wheel after each successive oscillation.

Fig 23



In fig. 23, the balance-wheel swinging from right to left, throws the convex side A D of the semicylinder before the tooth C of the escapement-wheel, and thus for the moment arrests it, while the side A E of the semicylinder has turned out of the way of the preceding tooth and has let it pass. The balance-wheel then swings from left to right, and the convex side A D of the semicylinder slides against the point of the tooth C. When the edge D of the semicylinder passes the point of the tooth, the latter in slipping over it gives to it a slight impulse, which restores to

Fig. 24.



the balance-wheel the small quantity of force which it lost by the previous reaction of the tooth upon its convex surface.

The side A E of the semicylinder is now thrown before the tooth C, the point of which having advanced through a space equal to the diameter of the semicylinder, is thrown against the concave surface of A E, as shown in fig. 24.

The balance-wheel now swinging again from right to left, the point of the tooth C slides upon the concave surface of the semicylinder A E, until the edge E comes to it. The tooth then slips over the inclined face of E, and in doing so gives the semicylinder and consequently the balance-wheel another slight impulse, restoring to it the force of which it deprived it while previously sliding upon its concave side.

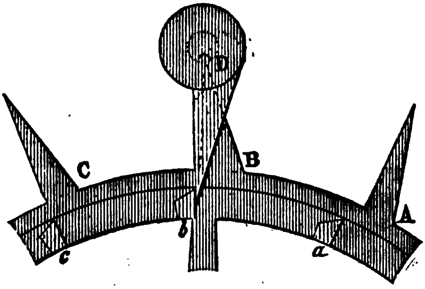
The explanation here given of the action of this form of escapement is well calculated to render the conditions which all escapements should fulfil intelligible. These arrangements are primarily directed to the regulation of the movement of the wheel-work, so as to secure its uniformity. This will obviously be accomplished provided that the escapement, whatever be its form, lets a tooth of the wheel pass for each oscillation of the balance-wheel. But owing to the friction of the axis of the balance-wheel, and of the pallets on the teeth of the escapement-wheel, and the resistance of the air, the range of its oscillations would be gradually diminished, so that at last it would not be sufficient to allow the successive passage of the teeth of the escapement-wheel, and the watch would stop unless some adequate means are provided by which the balance-wheel shall receive from the mainspring through the escapement-wheel as much force as it thus loses. All escapements accomplish this by the peculiar forms given to the edges of the pallets and the teeth of the escapement-wheel. In the present case, the object is attained by making the edge D round and the edge E inclined, and by giving to the teeth the form shown in the figure.

This form of escapement supplies a sufficiently good regulating power for the best sorts of pocket watches, and is attended with the advantages of allowing the works to be compressed within a very small thickness. It is the form most commonly used in the French and Swiss watches.

41. The form of escapement used in the best English made watches consists of an escapement-wheel, which partakes at once of the double characters of a spur and crown-wheel, and is hence called the duplex escapement.

The spur teeth, A, B, C, &c. (fig. 25), are similar in their form and arrangement to those of the cylindrical escapement described above. The crown teeth, *a*, *b*, *c*, &c., project from the face of the wheel, and have a position intermediate between the spur teeth. Upon the axle of the balance-wheel just above the plane of the escapement-wheel is fixed a claw pallet called the impulse pallet, which by the combination of the oscillations of the balance and the progressive motion of the escapement-wheel falls successively between the crown-teeth of the latter, receiving from their reaction as they escape from it, the restoring action which maintains the range of the oscillations of the balance-wheel.

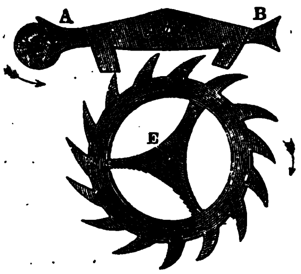
Fig 25.



Under the pallet and in the plane of the spur teeth is placed a small roller usually formed of ruby or other hard stone, having a notch on one side of it, into which the spur teeth successively fall. After any crown tooth, *a* for example passes the pallet, the corresponding spur tooth A falls into the notch of the roller, and this alternate action continues so long as the watch goes. It will be perceived therefore that the pallet and roller in the duplex escapement play the same part as the two edges of the semicylinder in the cylindrical escapement, and as the two pallets in the common recoil escapement (fig. 17).

The chief advantage claimed for this system is that there is but one pallet, and that the action does not require as perfect execution of the teeth of the escapement-wheel as other arrangements.

Fig. 26.



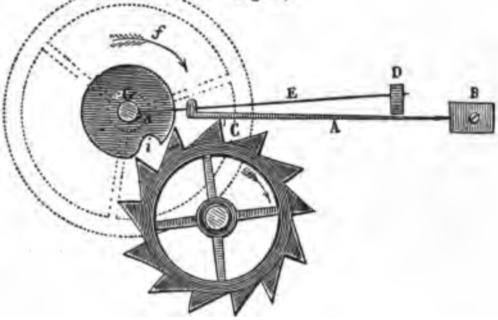
42. The lever escapement is much used for English pocket watches. A lever A B (fig. 26), with a notch at one end, is attached to the anchor C. A pin at *a*, on a disc D, on the verge or arbor of the balance, enters this notch at each vibration, and first moves the dead part of the pallet off the tooth of the scape-wheel E, and then receives an impulse, which restores the force it has lost, leaving another tooth

engaged in the opposite pallet. As the lever is detached from the balance, except for an instant at the middle of each vibration, the amount of friction is very small. Another advantage of this movement is, that it is but little liable to derangement, and when it is injured, is easily and cheaply repaired, while the duplex and cylindrical escapements are expensive to make, and can only be mended by such skilful workmen as are not often found, except in the metropolis or large towns.

43. In the class of portable timepieces used for the purposes of navigation, where the greatest attainable regularity of motion is required, an arrangement is adopted called the detached escapement. This system is represented in fig. 27.

Upon the arbor of the balance-wheel is attached a disc, in which there is a notch *i*. A smaller disc, G, is also attached to it, from which a small pin projects. By the oscillations of the balance-wheel the notch *i* and the pin oscillate alternately right and left.

Fig. 27.



A fine flexible spring, A, attached to a fixed block, B, carries upon it a projecting piece, C. To the block D is attached another fine spring E, which extends to the edge of the small disc G. The projecting piece C, is so placed that when the spring A is not raised, it encounters a tooth of the scapewheel, but when slightly raised it allows the tooth to pass. The spring E rests in a small fork behind the extremity of A, and presented downwards.

Now, let us suppose the balance-wheel to swing from left to right. The pin, projecting from the small disc G, coming against the end of the spring E, raises it; and this spring acting in the fork behind it raises the spring A, and therefore lifts the piece C, and liberates the tooth which that piece previously obstructed. The scape-wheel therefore advances, but before the next tooth comes to the place occupied by the former one, the balance swings back from right to left. The spring E no longer supported by the fork at the end of A, readily lets the pin pass, and the piece C returning to its former position, comes in the way of the succeeding tooth and stops it.

At the moment that the balance is about to commence its swing from left to right, and when the piece C is about to liberate the tooth which rests against it, another tooth behind it rests against the side of the notch *i* in the disc G, and when the escapement-wheel is liberated, and the swing of the balance from left to right is commencing, this tooth, pressing on the side of the notch *i*, gives it and the balance-wheel an impulse which is sufficient to restore to it all the force which it lost in the previous oscillation. Except at this moment the balance-wheel in this form of escapement is entirely free from all action of the mainspring.

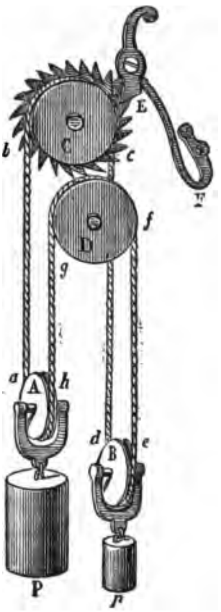
44. While a clock or watch is being wound up, the weight or mainspring no longer presses upon the catch nor upon the ratchet-wheel, through which the motion is imparted to the wheelwork. The motion of the hands is therefore suspended during the time occupied in winding up, consequently if the watch or clock keep regular time while it goes, it must lose just so much time as may be employed in the process of winding it up. Although this, in common clocks and watches, does not produce any sensible effect, the errors incidental to their rates of going generally exceeding it, yet in clocks used in observatories and in chronometers used for the purposes of navigation, where the greatest degree of regularity is required, provisions are made by which the motion of the clock or watch is continued notwithstanding the process of winding up.

Such expedients are called the MAINTAINING POWER.

One of the most simple arrangements by which this is accomplished in clocks moved by a weight is shown in fig. 28. The weight P, which is the moving power, is connected with another much smaller weight *p*, by means of an endless cord which passes over the grooves of a series of pullies, A, B, C, and D, of which A and B are moveable, and C and D fixed. The force with which P descends is the excess of its weight above that of *p*.

The pulley C, being prevented from revolving by the catch E during the descent of the weight P, and the cord being prevented from sliding upon its groove by the effects of its friction and adhesion, the parts *b a* and *c d*, which descend from the pulley C to the pulleys A and B, may be regarded as being virtually attached to fixed points at *b* and *c*, so that they cannot descend. This being the case, the weight P, descending by its preponderance over *p*, and consequently the weight *p* being drawn up, the part of the cord *c d* must pass over the pulley B, the part *e f* over the pulley D, and the part *g h* over the pulley A. In this way the parts *b a* and *g h* will be gradually lengthened as the weight P descends at the expense of the parts *c d* and *f e*, which will be shortened to an equal extent, so that the weight *p* will be raised through the same space as that through which the weight P is lowered. During this process the wheel D is kept in constant revolution, and the first wheel of the train of clock-work being fixed on its axle, a motion is imparted by it through that train to the hands.

Fig. 28.



When it is desired to wind up the clock, the hand is applied to the cord *c d*, which is drawn downwards, so that the fixed pulley revolves, the catch E dropping from tooth to tooth until the weight P has been raised to the highest, and the weight *p* has fallen to the lowest point. The parts *g h* and *f e* of the cord not being at all affected by this, the pulley D continues to turn as before by the effect of the preponderance of P, which acts as powerfully while it ascends as it did when it descended.

It appears, therefore, that, by this arrangement, the motion of the works and of the hands is not suspended during the process of winding up.

46. If the works of a watch be impelled by the force of a mainspring without a fusee, in the manner represented in fig. 17, it is evident that the movement must be suspended during the process of winding up, because the ratchet-wheel B, by which the force of the spring is transmitted to the works, is then relieved from the action of the catch *n o*. This defect may, however, in such case be removed by a very simple expedient. Instead of connecting the external extremity of the mainspring with a fixed point, let it be attached to the inside of a barrel surrounding it, and let the wheel C be attached to this barrel. In that case, when the axle of the ratchet-wheel is turned in winding up, and the ratchet-wheel, therefore, relieved from the action of the catch, the wheel C will be acted upon by the barrel, which will itself be impelled by the reaction of the external extremity of the spring which is attached to it, the winding up being effected only by the internal extremity.

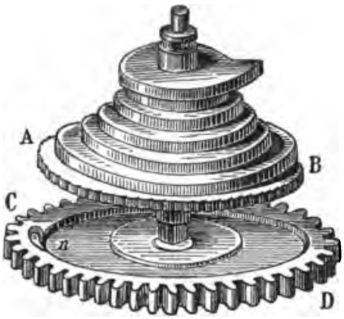
This is the arrangement generally adopted in chimney and table time-pieces, as constructed in France and Switzerland, and also in flat watches, in all of which the adoption of the cylindrical escapement (fig. 22) enables the constructor to dispense with the fusee.

It will, of course, be understood, that in such arrangements, while the wheel C is attached to the barrel, and by it to the external extremity of the mainspring, the ratchet-wheel B is attached to the axle T B (fig. 17), and by it to the internal extremity of the mainspring.

When a fusee is used, the ratchet-wheel being fixed upon its axis, and not on that of the barrel containing the mainspring, this method of obtaining a maintaining power is not applicable. In such cases, the object is attained by two ratchet-wheels upon the axle of the fusee, having their teeth and catches turned in opposite directions, one of them being impelled by a provisional spring, which only comes into play when the action of the mainspring is suspended during the process of winding up.

The fusee, with its appendages, as commonly constructed, without a maintaining power, is drawn in fig. 29, the grooved cone, with the ratchet-wheel attached to its base, being raised from the cavity in the toothed wheel C D, in which it is deposited, to show the arrangement more clearly, and in the edge of which the catch *n* is placed, so that it shall fall into the teeth of the ratchet-wheel.

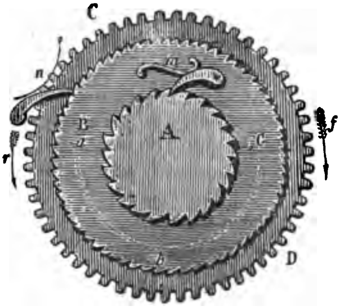
Fig. 29.



When the watch is being wound up, the chain passing from the barrel to the grooves of the fusee, the teeth of the ratchet-wheel, A B, pass freely round the cavity, the catch *n* falling from tooth to tooth, and producing the clicking noise already noticed. But when the watch is going, the tension of the chain draws the fusee and the ratchet-wheel attached to it round in the contrary direction, and, pressing the teeth of the ratchet-wheel against the catch *n*, carries round the wheel C D, which gives motion to all the other wheels, and through them to the hands. Now, it will be evident, that when the watch is being wound up, and the catch *n* relieved from the pressure of the teeth of the ratchet-wheel, no motion will be imparted to C D, and consequently the movement of the entire works will be suspended.

The modification by which a maintaining power is obtained by the combination of two contrary ratchet-wheels, is shown in fig. 30, where C D is the first wheel of the train from which the watch receives its motion. The ratchet-wheel A is fixed upon the base of the fusee, so as to move with it. The catch, *m*, which is pressed by a spring into the teeth of this ratchet-wheel, is attached to the second ratchet-wheel B, so that when A is carried round by the chain acting on the fusee, it must carry the wheel B round with it in the direction of the arrow *f*. The wheel B is connected with the wheel C D by a semicircular spring *a b c*, which is attached to the wheel C D at *c*, and to the wheel B at *a*. The catch, *n*, which falls into the teeth of the ratchet-wheel B, is attached to a fixed point on the bed of the watch.

Fig. 30.



While the watch is going, the wheel B, driven by the fusee, draws after it the spring *a b c*, bending it round to a certain extent, and this spring acting at *c*, on the wheel C D, draws it round in the direction of the arrow *f*. Now, let us suppose that the watch is being wound up. The ratchet-wheel A, being turned by the key in the direction of the arrow *r*, the catch *m* falls from tooth to tooth, and the force it before received from the ratchet-wheel A is suspended. But the spring *a b c* has been drawn from its form of equilibrium, to a certain small extent, in drawing round after it the wheel C D, as already stated, and it has still a tendency to draw that wheel after it, so as to recover its form of equilibrium. In doing this, it will continue to act upon the wheel C D, and to carry it round while the action of the fusee upon it is suspended during the process of being wound up. The spring *a b c* is so constructed as to act thus for an interval more than is necessary to wind up the watch.

46. From what has been explained, it will be observed, that timepieces in general are constructed with one or other of two moving powers, a descending weight, or a mainspring, and with one or other of two regulators, a pendulum or a balance-wheel. These expedients are variously adopted and variously combined, according to the position and circumstances in which the timepiece is used, and the purpose to which it is appropriated.

A descending weight as a moving power, combined with a pendulum as a regulator, supply the best chronometrical conditions. But the weight can only be used where a sufficient vertical space can be commanded for its ascent and descent, and neither it nor the pendulum is applicable except to timepieces which rest in a fixed and stable position.

In the case of timepieces whose position is fixed, but where the vertical space for the play of the weight cannot be conveniently obtained, the mainspring is applied as a moving power, combined with the pendulum as a regulator. Chimney and table clocks present examples of this arrangement. The height being limited, it is necessary also in these cases to apply short pendulums. The length of a pendulum which vibrates seconds being about 39 inches, such pendulums can only be used where considerable height can be commanded.

It has been shown, that the lengths of pendulums are in the proportions of the squares of the times of their vibration. It follows, therefore, that the length of a pendulum which would vibrate in half a second, will be one-fourth the length of one which vibrates in a second, and since the latter is 39 inches, the former must be 9¾ inches. Such a pendulum can therefore be conveniently enough applied to a chimney or a table clock high enough to leave about ten inches for its play.

The pendulum is so good a regulator, and the anchor-escapement renders it so independent of the variation of the moving power, that in timepieces where it is combined with a mainspring a fusee is found to be unnecessary. In such cases, therefore, the axis of the first wheel is placed in the centre of the mainspring, as represented in fig. 17.

47. The cylindrical escapement, shown in fig. 22, is nearly as independent of the variation of the moving power as the pendulum, and therefore in common watches, where this escapement is used, the fusee is dispensed with.

In the class of timepieces called chronometers, used for the purposes of navigation, and in general for all purposes where the greatest attainable perfection is required in a portable timepiece, all the expedients to insure regularity are united, and accordingly the detached escapement is combined with fusee and mainspring.

Besides the expedients above mentioned, for insuring uniformity of rate, provisions are made in the most perfect chronometers to prevent the variations of rate which would arise from the expansion and contraction of the metal composing the balance-wheel by the variation of temperature. These expedients are very various; but in general they consist of contrivances by which the expansion of the rim of the wheel causes a part of it so to bend, as to throw a heavier part nearer to the centre, to compensate for the increased distance of another part produced by its general enlargement.

48. Marine chronometers are usually suspended in a box on gimbals, like those which support the ship's compass. The balance-wheel usually vibrates in half seconds, being a much slower rate than that of common watches. They are of immense utility in navigation, and especially in long voyages. See Tract on "Latitudes and Longitudes," Museum, vol. i. p. 97.

49. In observatories where stationary timepieces can be used, the clock moved by weights and regulated by a pendulum is invariably adopted. The pendulum, in such cases, is always so constructed that its rate of vibration shall not be affected by variations of temperature. This is accomplished usually by constructing it of two different kinds of metal, which are differently affected by heat, one being more expansible than the other. They are so arranged that the expansion of one shall elevate the centre of gravity, while that of the other lowers it, and the two effects are made to compensate each other, so that, however the temperature may change, the rate of vibration will remain the same.

50. In clocks adapted for domestic and public use, it is found desirable that they should give notice of the time, not only to the eye, but to the ear; and for that purpose a bell is attached to them, which tolls at given intervals, the number of strokes being equal to that of the units in the number expressing the hour. This appendage is called the STRIKING TRAIN.

The striking train, though connected with that which moves the hands, is quite independent of it, having its own moving and regulating power, and its own system of wheels by which the effect of the moving power is submitted to the regulator, and transmitted to the tongue of the bell.

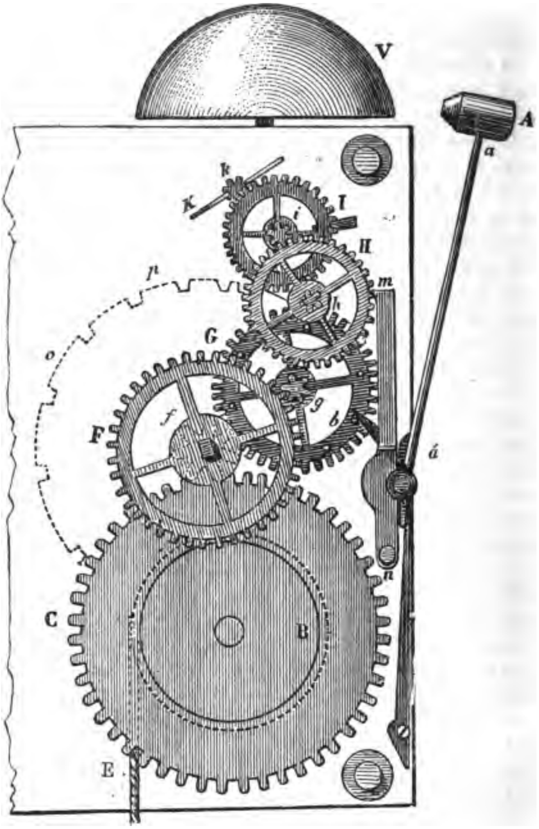
Unlike the train which moves the hands, the striking train is not in continual motion. Its motion is always suspended, except at the particular moment at which the clock strikes. The mechanism partakes of the character of an alarum, being stopped by a certain catch until the hands point to some certain hour, and then being set free by the withdrawal of the catch. It remains free, however, only so long as is necessary for the tongue or hammer to make the necessary number of strokes upon the bell, after which the catch again engages itself in the striking mechanism, and stops it.

Some clocks only strike the hour. Others mark the half hours, and others the quarters, by a single stroke.

The general principle of the striking mechanism will be rendered intelligible by fig. 31, which represents it in the case of a common clock moved by a weight.

The weight suspended from the cord E moves the train in the same manner as in the case of the train which moves the hands. The motion of the first wheel, C, is transmitted to the last wheel, I, which corresponds to the escapement-wheel by the intermediate wheels and pinions, *f*, F, *g*, G, *h*, H, and *i*. The wheel I drives

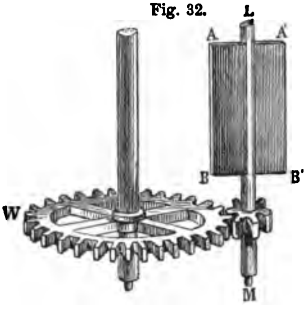
Fig. 31.



the pinion *k*, upon the axle of which is fixed the regulator K. This regulator is a fly, a side view of which, upon a larger scale, is shown in fig. 32.

The pinion, which is made to revolve by the wheel W, gives a motion of rotation to the fly AA′ B′B, which consists of a thin rectangular plate of metal, along the centre of which the prolongation M L of the axle of the pinion is attached. The flat surfaces of the fly, revolving more or less rapidly, strike against

Fig. 32.



the air, which resists them with a force which increases in the proportion of the square of the velocity of the rotation. Thus, if the velocity of rotation be increased in a two-fold ratio, the resistance to AA′ B′B is increased in a four-fold ratio; if the rotation be increased in a three-fold ratio, the resistance is increased in a nine-fold ratio, and so on. It is evident, therefore, that by this very rapid increase, the resistance to the motion of the train must soon become equal to the descending force of the weight, and then the motion will become uniform; for if it were to increase, the resistance would exceed the force of the weight, and would slacken the rate of motion; and if it were to decrease, the resistance being less than the force of the weight, the latter would accelerate the motion. In either case the motion would immediately be rendered uniform.

Projecting from the face of the wheel H (fig. 31) there is a small pin which rests upon the end *m* of a lever *m n*, which turns upon the centre *n*. The lever *m n* when in this position stops the motion of the striking train. Behind the same lever *m n*, and projecting from it, there is another piece, which in the position represented in the figure rests in a notch of the wheel *o p*, lying behind the striking train, and indicated in the figure by dotted lines. Around the edge of this wheel there is a series of similar notches at unequal distances, determined in the manner which we shall presently explain.

Upon the face of the wheel G, at equal distances one from another surrounding it, a series of pins project, which, as the wheel turns, successively encounter a lever *b*, which plays upon a centre *a*. Upon the same centre *a* is fixed the handle *a a′* of the hammer A by which the bell V is struck. A spring fixed upon the same centre *a* causes the lever *b* to rest in the position represented in the figure, and to return to that position if raised from it. The hammer handle *a a′* is made either elastic itself or is provided with a like spring.

When the wheel G is made to revolve at a uniform rate by the weight E, regulated by the fly K, the pins projecting from the face of the wheel G encounter successively the lever *b*, and raising it, throw back the handle *a a′* of the hammer which is in connection with the lever *b*. After the pin has passed the lever *b* the latter is brought back with a jerk by the action of the spring, and the hammer A receiving the same jerk strikes upon the bell V and instantly recoils from it; and if the wheel G continues to revolve, one pin after another upon it will encounter the lever *b*, and the hammer A will make a stroke upon the bell each time that a pin passes the lever.

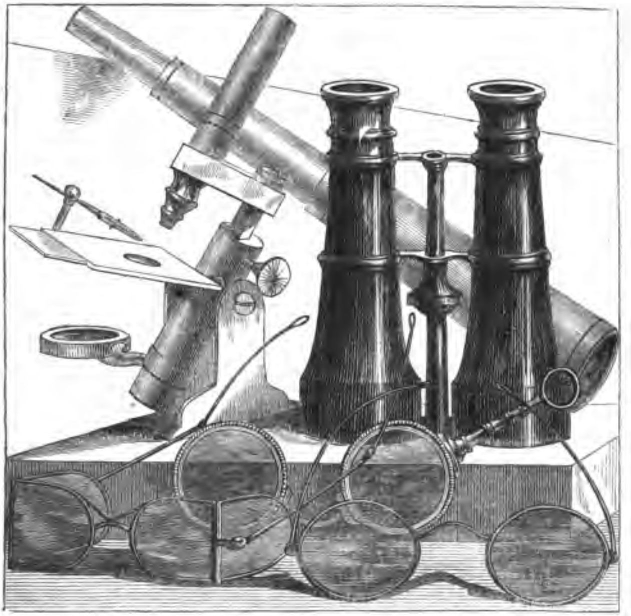
The wheel H is so constructed that it will make one revolution in the interval between two successive strokes of the bell, or what is the same, in the interval between the moments at which two successive pins pass the lever *b*.

In the train which moves the hands, an expedient is provided by which each time that the minute hand passes twelve upon the dial, the lever *m n* is thrown back from the position which it has in fig. 31, and the top *m* being withdrawn from under the pin upon the wheel H, that wheel and the entire striking train is liberated and set in motion. At the same time the piece is taken out of the notch in which it rested on the wheel *o p*, and that wheel, in common with the other parts of the striking train, is put in motion.

For every complete revolution that the wheel H makes, the hammer A makes a stroke upon the bell, and the motion of H and of the entire striking train will continue until the end *m* of the lever *m n* again comes under the pin projecting from the face of H. During the motion, the lever *m n* is kept back by the edge of the wheel *o p* acting against the piece projecting from the lever *m n*. But when the wheel *o p* has turned so as to bring the next notch to the projecting piece, it will be thrown into the notch, and the end *m* of the lever *m n* coming under the pin projecting from the wheel H, the motion of the train will be suspended.

Now, it will be evident from what has been stated, that when the lever *m n* is thrown back by the works, it is kept back by the edge of the wheel *o p* acting against the projecting piece, and so long as it is thus kept back, the striking train continues to move and the hammer continues to strike the bell. But the duration of this motion will depend on the space between the notches on the wheel *o p*, since it is while that space upon the edge passes under the projecting piece on *m n* that the end *m* of the lever *m n* is kept back so as to be out of the way of the pin projecting from the wheel H. These spaces between the notches are therefore so proportioned, one to another, that the lever *m n* at each hour is held back a sufficient time for the hammer to make upon the bell the number of strokes denoting the hour and no more.

The arrangement for striking half-hours and quarters is based upon similar principles.



COMMON THINGS.

SPECTACLES.

1. **Their general utility.—2. Should therefore be generally understood.—3. Vision.—4. Blindness.—5. Defective sight.—6. Long and short sight.—7. Remedy.—8. Spectacles.—9. Effect of convex lenses.—10. Of concave lenses.—11. Focal length of a lens.—12. Varies with distance of object.—13. Peculiarities of vision in short sight explained.—14. In long sight.—15. The mounting of spectacles.—16. Periscopic spectacles.—17. Both eyes have not always the same power of vision.—18. Ophthalmometer.—19. Application of it in selecting glasses.—20. Curious defects of vision.**

1. SPECTACLES are incontestably the most universally useful gift which optical science has conferred on mankind. More wonderful instruments abound. The miracles disclosed to human vision by the telescope and the microscope are known to all. To such marvels, spectacles lay no claim. But to compensate for this

their utility is ubiquitous. In the palace of the monarch and in the cottage of the peasant their beneficent influence is equally diffused. It is remarkable also, that, unlike most other productions of art and science, cost can add nothing to their perfection. Those of the millionaire may be mounted in gold, and those of the humble labourer in iron; but the optical medium, the glass lenses to which they owe their perfection, must be the same.

2. It is good that an object of such unbounded usefulness should be generally understood. The more completely and clearly the principles on which the application of the instrument depends are comprehended, the greater will be the extent of the benefit which each individual will derive from them, and the less frequent will be the inconveniences and evils resulting from their abuse.

Before it is possible, however, to comprehend the principle and the right use of spectacles, it is indispensably necessary to be acquainted with the structure and functions of the eyes, and such readers as have not already obtained that preliminary knowledge are referred for it to our tract on that subject.

The defects incidental to the sense of sight have been briefly noticed in that tract, and the optical expedients by which remedies have been obtained for them have been stated. We propose here to resume that subject, and to present other and more developed illustrations of it.

3. When an object is placed at a certain distance from the eye, a small picture or image, as it is called, of the object is produced upon the posterior surface of the coating which lines the inside of the spherical shell, called the eye-ball. This coating, upon which the picture is thus formed, is called the retina.

It is this picture on the retina which enables us to see the object. If this picture be obscure, falsely coloured, confused, or indistinct, our vision of the object will also be obscure, falsely coloured, confused, or indistinct.

In its natural and healthy state the structure of the eye is such that the pictures of all objects presented to it thus formed upon the retina, are clear, rightly coloured, and perfectly distinct in form and outline. In individual cases, however, eyes are variously defective.

4. If the coats and humours, through which the rays of light, proceeding from external objects ought to pass, be not in any degree transparent, no picture whatever is formed on the retina, and the subject is blind.

5. If the coats and humours are imperfectly transparent the picture will be obscure, being formed only by the rays of light partially transmitted through the humours.

It sometimes happens that the humours, like coloured glass or coloured liquids, transmit only light of a particular colour. In that case the image on the retina is falsely coloured, the false colours depending on the colour of the humours.

For these several classes of defects spectacles are wholly inefficacious.

6. When the humours are perfectly transparent and free from colour, the picture which they would produce may fall not immediately upon the retina, but at a distance more or less considerable before or behind it. In that case the effect produced upon the retina will be a picture more or less confused and indistinct. It will be so much the more indistinct as the place where the distinct picture would be formed is more distant from the retina.

If the place of the distinct picture be before the retina, the defect is owing to the eye having too great refracting power upon the rays of light. If it be behind the retina, it is owing to the refracting power being too feeble.

The former is called SHORT SIGHT, and the latter LONG SIGHT, or WEAK SIGHT.

7. For these defects of vision, which are by far the most common, spectacles supply a perfect remedy.

They accomplish this by the effect they are capable of producing upon the place of the picture. If the eyes be weak-sighted, and consequently the picture is formed *behind* the retina, spectacles are applied which have the effect of bringing forward the picture to the retina. If they be short-sighted, so that the picture is formed *before* the retina, spectacles are applied which have the effect of throwing it back to the retina.

8. Spectacles consist of circular discs of glass called lenses, the surfaces of which are brought by grinding and polishing to a convex or concave form.

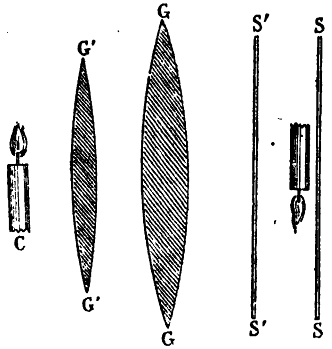
9. If a convex lens of this kind be placed before the eye, it will have the effect of bringing forward the picture formed within the eye. A concave lens, placed in the same manner, will have the contrary effect of throwing it backward.

It will be easy for any person to convince themselves that such glasses have the properties here described.

Let a convex disc of glass or lens, G G, fig. 1, be placed before a candle, C, and let a white paper screen be placed behind G G, and moved towards and from it until a position is found, such as S S, in which a distinct inverted picture of the candle will be seen upon it. If the screen be now moved to S′ S′, a little nearer to G G, so that the place of the distinct picture shall be *behind* it, an indistinct picture of the candle will be seen upon the screen.

In this case the lens G G may be imagined to represent the eye of a weak-sighted person, the candle C a visible object, and the screen S′ S′ the retina, upon which an indistinct image of the object is depicted, and S S the place behind the retina, at which the picture would be distinct.

Fig. 1.



Now if another convex lens, G′ G′, which may represent a spectacle glass, be placed before G G, it will have the effect of bringing forward the place of the distinct image, and it will bring that place more or less forward according as G′ G′ is more or less convex. It is easy to conceive that its convexity may be such that the image of the candle will be brought exactly to the position of the screen S′ S′.

Thus it appears, that if the screen be misplaced, with relation to the distinct picture of the candle, so as to be before it, a glass G′ G′ of suitable convexity, placed before G G, will bring the distinct picture forward to the position of the screen, upon which it will then be seen.

This is a simple experiment which any one can try with a candle, a sheet of paper, and two spectacle glasses.

It perfectly represents the case of a weak-sighted person, and the benefit they derive from convex spectacle glasses.

If, however, the lens G′ G′ be too convex, the picture will be brought too much forward, and it will be formed not on the screen S′ S′, but before it, and will consequently be indistinct. If, on the contrary, the lens G′ G′ be not sufficiently convex, the picture will not be brought so forward as the screen S′ S′, and will still be indistinct upon it.

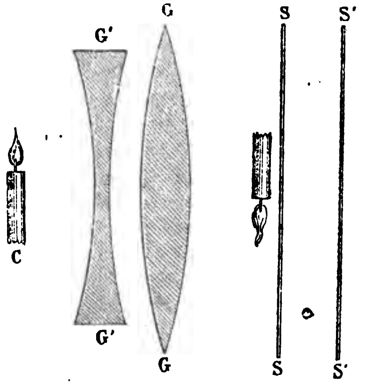
Thus, between the relative positions of the distinct picture of the candle, that of the screen S′ S′, and the convexity of the lens

G′ G′, there is a certain relation, such that only one particular degree of convexity will bring the distinct picture upon the screen.

In the same manner, it follows that between the relative positions of the retina, of the distinct picture formed behind it, and the convexity of the spectacle glasses, there is a certain fixed relation, such that such glasses only as have a particular convexity will bring the distinct picture on the retina, and produce clear and distinct vision.

10. Let us suppose now that the screen is placed as at S′ S′, fig. 2, *behind* the position at which the distinct picture of the candle is formed. In this case it is required to throw the distinct picture *backwards*, and as it was brought forwards by the interposition of a *convex* glass, it will be thrown *backwards* by the interposition of a *concave* glass. Such a lens, G′ G′, having the proper degree of concavity, being therefore placed before G G, the distinct image will be seen upon the screen S′ S′.

Fig. 2.



As in the former case, there is a certain relation between the relative positions of the distinct picture of the candle, of the screen S′ S′, and the concavity of the lens G′ G′, so that only one particular degree of concavity will throw back the distinct picture to the screen.

As in the former case, this experiment illustrates the case of a short-sighted eye, and the remedy affixed by the interposition of a concave glass. The lens G G represents the eye, S′ S′, the retina, and S S the place before it where the distinct picture is formed when no glass is used. When G′ G′ is interposed between the object and the eye, the distinct image is thrown back to S′ S′, the place of the retina.

11. The place at which the distinct image of a distant object is formed by a lens, or by any other optical medium equivalent to a lens, is called the FOCUS of the lens, and the distance of the focus from the lens is called the FOCAL LENGTH of the lens.

When the structure of the eye is perfect, therefore, its focus must be on the retina, and its focal length will be the interior diameter of the eye-ball. When the focal length of the eye is greater than this the focus is behind the retina, and the eye is weak-sighted or long-sighted. When the focal length is less, the focus is before the retina, and the eye is short-sighted.

12. If an object, a candle for example, placed before a convex lens, be moved towards the lens, the place at which its distinct picture is formed, that is its focus, will move from the lens, so that the nearer the object is to the lens the further will its picture be from it. It is easy to verify this by means of the candle, the lens, and the screen. As the candle is moved nearer and nearer to the lens, the place at which the screen will receive a distinct picture of the flame will be farther and farther from the lens, and in the same manner if the candle, being placed very near the lens, be gradually removed farther and farther from it, the place at which the screen will receive a distinct picture will be nearer and nearer to the lens.

This will explain some circumstances attending the vision of near-sighted and weak-sighted persons, which are familiar to every one.

13. When a near-sighted person looks at a distant object, its focus is within the eye-ball, before the retina, on which, consequently, the picture is indistinct. But if the object be brought gradually nearer and nearer to the eye, its distinct picture will move more and more backward, according to what has been just shown, and it will consequently approach nearer and nearer to the retina, until at length the object is brought so near the eye, that the distinct picture exactly falls upon the retina. The vision is then perfect.

It will thus be understood why near-sighted persons can see objects distinctly, only when they are brought within a certain distance of the eye. The more removed the focus of their eye is from the posterior part, the nearer an object must be brought before the picture is thrown back to the retina, and the person is said to be so much the more near-sighted.

Concave spectacle-glasses, in this case, have the same effect in throwing back the picture as the proximity of the object, and with such spectacles the object can consequently be seen distinctly without being brought near to the eyes. If, when the spectacles are interposed, the object be brought as near the eyes as would be necessary for distinct vision without spectacles, the vision will be indistinct; because, in that case, the effect of the glasses will be to throw the distinct picture behind the retina, which, without the glasses, would have been upon it.

When persons are not very short-sighted, they generally read or work without spectacles, but require their aid when they walk abroad or move in society in large rooms, because the book or the objects of their work can, without inconvenience, be placed at the moderate distance from their eyes which is sufficient to throw the focus back upon the retina, but the more distant objects at which they look when walking abroad or in large rooms are beyond the proper limit of distance, and the focus, being before the retina, must be thrown back by concave spectacles.

14. When an object is placed near the eyes of a weak-sighted person, the focus is behind the retina, and the picture on the retina is consequently indistinct. If the object be gradually removed to a greater and greater distance, the focus, according to what has been explained, will approach the retina nearer and nearer, and, if the sight be not too weak, it will come upon the retina when the object is removed to a certain distance from the eye. In this case, however, owing to the greater distance of the object, stronger illumination is required, and it is found, accordingly, that when weak-sighted persons hold a book at arms-length from the eyes, they are obliged, at the same time, to place a strong light near the page.

Eyes, which are not of very weak sight, have sufficient power to bring the picture of all objects, whose distance exceeds three or four feet, upon the retina. But for nearer objects, the picture, being behind the retina, requires to be brought forward by the interposition of convex spectacles. The nearer the object looked at is, the more convex ought the glasses to be, and hence it comes that very weak-sighted persons require to be provided with more than one pair of spectacles, those adapted to more distant objects being less convex, and those adapted to nearer objects more so.

When the weakness of sight is so limited that the pictures of distant objects fall upon the retina, those only of nearer ones being behind it, the eye is said to be FAR-SIGHTED, in contradistinction to the opposite defect, by which distinct vision is only obtained by the closer proximity of the object.

15. Spectacles consist of two glass lenses mounted in a frame so as to be conveniently supported before the eyes, and to remedy the defects of vision of naturally imperfect eyes.

Whatever be the defects of sight which they may be used to remove, it is evident that the lenses ought to be so mounted that their axes shall be parallel, and that their centres shall coincide with the centres of the pupils when the optical axes are directed perpendicular to the general plane of the face, that is to say, when the eyes look straight forward.

These conditions, though important, are rarely attended to in the choice of spectacles. If spectacles be mounted in extremely light and flexible frames, the lenses almost invariably lose their parallelism, and their axes not only cease to be parallel, but are frequently in different planes. Spectacles ought therefore to be constructed with mounting sufficiently strong to prevent this derangement of the axes of the lenses, and in their original construction care should be taken that the axes of the lenses be truly parallel.

In the adaptation of spectacles it is necessary that the distance between the centres of the lenses should be precisely equal to the distance between the centres of the pupils. The clearest vision being obtained by looking through the centres of the lenses, the eyes have a constant tendency to look in that direction. Now if the distance between the centres of the lenses be greater than the distance between the centres of the pupils, the eyes having a tendency to look through the centres of the lenses, their axes will cease to be parallel, and will diverge as in the case of an outsquint. On the other hand, if the distance between the centres of the lenses be less than the distance between the centres of the pupils, there will, for a like reason, be a tendency to produce an insquint.

I have myself known persons of defective sight, who had never been able to suit themselves with spectacles, and concluded that they had some defect which spectacles could not remedy. Upon observing the form of their heads, I found, in each case, that the eyes were more distant asunder than eyes generally are, while the spectacles they used, being those made with the lenses at the usual distance, were never, and never could be, so placed as to be concentrical with the eyes, and hence arose the discomfort attending their use. In all such cases I removed the inconvenience by measuring the distance between the centres of the eyes, and causing proper glasses to be mounted in frames, so that the distance between their centres should correspond with the distance between the centres of the eyes.

I would therefore advise every one who uses spectacles to cause the distance between the centres of their eyes to be exactly measured, and to select for their spectacles mountings corresponding with this distance.

16. The most perfect vision with spectacles is produced when the eye looks in the direction of the axis of the lenses, and more or less imperfection always attends oblique vision through them. Persons who use spectacles, therefore, generally turn the head, when those whose sight does not require such aid merely turn the eye.

To diminish this inconvenience, the late Dr. Wollaston suggested the use of menisci, or concavo-convex lenses, instead of double concave or double convex lenses with equal radii, which up to that time had been invariably used.

Sections of lenses of this kind are given in figs. 3 and 4. In fig. 3, the convexity A′ B′ C′, of which the centre is O′, is greater than the concavity A B C, of which the centre is O, and the effect of the lens is the same as that of a convex lens. Such glasses are therefore adapted for weak sight. In fig. 4, on the contrary, the concavity A B C, of which the centre is O, is greater than the convexity A′ B′ C′, of which the centre is O′, and the effect of the lens is the same as that of a concave glass. Such glasses are therefore adapted to short sight.

Fig. 3.

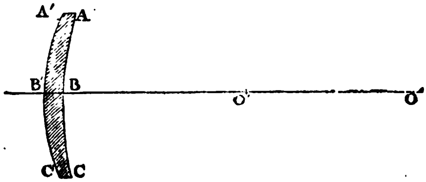
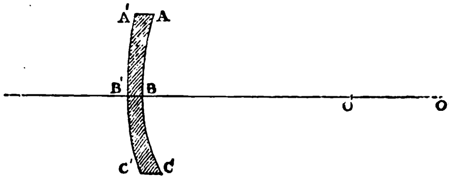


Fig. 4.



The effect of these, as compared with double convex and double concave glasses, is, that objects seen obliquely through them are less distorted and, consequently, that there is a greater freedom of vision by turning the eye without turning the head, from which property they were named *periscopic spectacles.*

17. In the selection and adaptation of spectacles, it is invariably assumed without question, that the two eyes in the same indi-

vidual have exactly the same refracting power. That this is the case is evident, from the fact that the lenses provided in the same spectacles have invariably the same focal length.

Now although it is generally true that the two eyes in the same individual have the same refractive power, it is not invariably so; and if it be not, it is evident that lenses of equal focal length cannot be at once adapted to both eyes.

When the difference of the refractive power of the two eyes is not great (which is generally the case when a difference exists at all), this inequality is not perceived. By an instinctive act of the mind, of which we are unconscious, the perception obtained by the more perfect of the two eyes in case of inequality is that to which our attention is directed, the impression on the more defective eye not being perceived.

It might be expected, however, that the inequality would become apparent, by looking alternately at the same object with each of the eyes, closing the other; but it is so difficult to compare the powers of vision of the two eyes when they are not very unequal, by objects contemplated at different times, even though they should be exhibited in immediate succession, that this method fails.

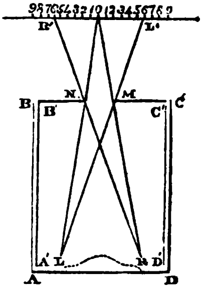
18. My attention having been directed to this question, I contrived an apparatus, which may not inaptly be called an *Ophthalmometer*, by which the least difference in the powers of vision of the two eyes may be rendered immediately apparent.

The principle I adopted for this purpose, resembles that which has been otherwise applied with success in photometers. I have so arranged the apparatus, that two similar objects similarly illuminated shall be at the same time visible in immediate juxtaposition, the one by the right eye being invisible to the left eye, and the other by the left eye being invisible to the right eye.

This apparatus consists of a small box, A B C D, fig. 5, about five inches in width, A D, ten inches in length, A B, and six inches in height. Within this there slides another box, A′ B′ C′ D′, made nearly to fit it, but to move freely within it, the interior of this box being blackened, or lined with black velvet. In the end, B′ C′, is a rectangular aperture, the length of which M N is about an inch, and the height about half an inch; the length, however, being capable of being augmented and diminished by slides. Opposite to the end of the box B C is a white screen, on which is traced a horizontal line parallel and opposite to the opening M N, and marked with a divided scale, the 0 of which is opposite to the centre of the aperture M N, and the divisions upon which are numbered in each direction from 0 by 1, 2, 3, 4, 5, 6. . . . .

Let us suppose the eyes now applied at R and L. Let the sliding interior box B′ C′ be moved until, on closing the left eye, the division 0 of the scale coincides with the edge M of the opening, and at the same time, by closing the right eye, the same division 0 of the scale coincides with the edge N of the opening. It will be always possible to make this adjustment, provided the eyes are placed centrally opposite the opening M N, which may be easily managed by cutting in the edge of the box A D an opening to receive the bridge of the nose. This arrangement being made, it is clear that if we close the left eye we shall see the space upon the scale included by the lines R N and R M continued to the screen R′ L′. Let us suppose this space to include the six divisions of the scale from 0 to 6. If we close the right eye, we shall see with the left eye the six divisions of the scale to the right of 0. Now if we open both eyes and look steadily with them through the aperture M N, giving no more attention to the impression on the one than on the other, we shall see the twelve divisions of the scale, six to the right and six to the left of 0; the six divisions to the left of 0 being seen only with the right eye, and the six divisions to the right of 0 being seen only with the left eye.

Fig. 5.



In this way we have two similar objects, similarly illuminated and of equal magnitude, in immediate juxtaposition, the one seen by the right and the other by the left eye; and any difference in their distinctness, quality, brilliancy, or colour, will be as clearly and instantly perceivable as the comparative brilliancy of spaces illuminated by two different lights in the photometer. I have already experimented with this apparatus upon my own eyes, the result of which is, that I find that the sight of the right eye is much better than that of the left, the figures to the left of 0 being always more distinct than those to the right of it: but, what is more remarkable, I find that the transparency of the humours of the right eye is more perfect than that of the humours of the left eye, for the space to the right of 0 always appears less bright than the space to the left of it.

19. To apply this instrument for the purpose of adapting spectacle lenses to eyes of unequal powers of vision, it is necessary first to ascertain the existence of the inequality of power in the manner already explained. It would then be necessary to provide two distinct screens on which similar scales might be drawn, so that they might be placed at different distances from the aperture M N. Let their relative distances be then determined, so that the two eyes would see the scales with equal distinctness. These distances will then represent the focal lengths of the divergent lenses which it would be necessary to provide for the eyes, so as to make them see different objects with equal distinctness.

In the case of weak-sighted eyes, this method will not be applicable. In that case let the two screens be placed at equal distances from the aperture M N, and let lenses be selected for each eye separately, closing the other, so as to give a distinct perception of the scales. The two lenses being then simultaneously applied to the eyes, let the scale be viewed with both eyes open. If the lenses be adapted to correct the defect of vision, the two parts of the scale to the right and to the left of 0, seen at the same time by each eye alone, will appear of uniform brilliancy and distinctness.

If defective eyes were tested by this method, I believe it would be found that inequality of vision would be much more common than is generally supposed, and accordingly the adaptation of spectacles would be considerably improved.

20. Cases occur not only in which the comparative powers of vision of the two eyes differ, but in which the power of vision, even of the same eye, is different when estimated in different directions.

I have known short-sighted persons who were more short-sighted for objects taken in a vertical than in a horizontal direction. Thus with them the height of an object would be more perceptible than its breadth, and in general, vertical dimensions more clearly seen than horizontal. This difference arises from the refractive power of the eye taken in vertical planes being different from the refractive power taken in horizontal planes; and the defect is accordingly removed by the use of lenses whose curvatures, measured in their vertical direction, is different from their curvature measured in their horizontal direction. The lenses, in fact, instead of having *spherical* surfaces, have *elliptical* surfaces, the excentricities of which correspond with the variation of the refractive power of the eye.

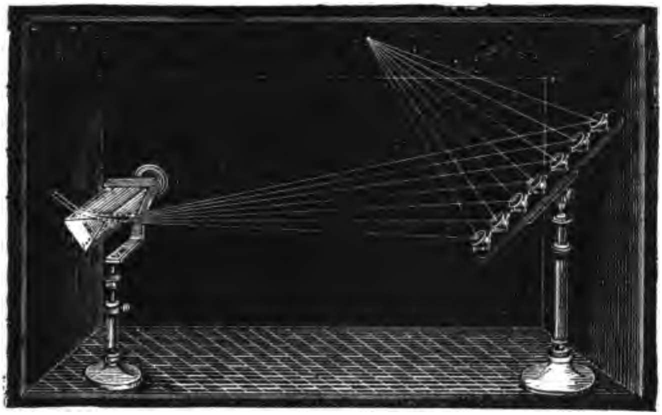


Fig. 10.—NEWTON'S EXPERIMENT SHOWING THE RECOMPOSITION OF LIGHT.

COMMON THINGS.

COLOUR.

CHAPTER I.

1. Colours depend upon reflected lights.—2. Bodies luminous and non-luminous. —3. Luminaries. — 4. Non-luminous bodies. — 5. Transparency and opacity.—6. Transparency never perfect.—7. Opacity never perfect.—8. Bodies rendered visible by reflected light.—9. Irregular reflection.—10. Reflecting powers vary.—11. The blackest body reflects some light—12. Irregular reflection necessary to vision. —13. Use of the atmosphere in diffusing light.

1. THE colours of objects, natural and artificial, depend on the light which they have the peculiar property of reflecting. A red object is one which is capable of reflecting red light exclusively, or at least in a much larger proportion than the lights of other colours. A green object is one which has the property of reflecting a predominance of green light, and so on.

These effects, familiar as they are to every one from the moment the senses are excited by external objects, are, nevertheless, very imperfectly understood, and often altogether misunderstood. Indeed, it was not until the time of Newton that the true physical cause of the colours of visible objects was fully explained.

The phenomena depend on certain properties of light, which must be understood before it is possible that the causes of colour can be rightly comprehended.

2. In relation to the production of light, bodies are considered as luminous and non-luminous.

3. Luminous bodies, or luminaries, are those which are original sources of light, such, for example, as the sun, the flame of a lamp or candle, metal rendered red-hot, the electric spark, lightning, and so forth.

Luminaries are necessarily always visible when present, provided the light they emit be strong enough to excite the eye.

4. Non-luminous bodies are those which themselves produce no light, but which may be rendered temporarily luminous when placed in the presence of luminous bodies. These cease, however, to be luminous, and therefore visible, the moment the luminary from which they borrow their light is removed. Thus the sun, placed in the midst of the planets, satellites, and comets, renders these bodies luminous and visible; but when any of them is removed from the solar influence by the interposition of any object not pervious by light, they cease to be visible, as is manifest in the case of lunar eclipses, when the globe of the earth is interposed between the sun and moon, and the latter object is therefore deprived of light. A candle or lamp placed in the room renders the walls, furniture, and surrounding objects temporarily luminous, and therefore visible; but if the candle be screened by any object not pervious to light, those parts of the room from which light is intercepted would become invisible, did they not receive some light from the other parts of the room still illuminated. If, however, the candle or lamp be completely covered, all the objects in the room become invisible.

5. In relation to the propagation of light, bodies are considered as transparent and opaque. Bodies through which light passes freely are called transparent, because the eye placed behind them will see such light through them. Bodies, on the contrary, which do not admit light to pass through them, are called opaque; and such bodies consequently render a luminary invisible if interposed between it and the eye.

Transparency and opacity exist in various bodies in different degrees. Glass, air, and water are examples of very transparent bodies. The metals, stone, earth, wood, &c. are examples of opaque bodies.

Correctly speaking, no body is perfectly transparent or perfectly opaque.

6. There is no substance, however transparent, which does not intercept some portion of light, however small. The light is thus intercepted in two ways; first, when the light falls upon the

surface of any body or medium, a portion of it is arrested, and either absorbed upon the surface, or reflected back from it; the remainder passes through the body or medium, but in so passing more or less of it is absorbed, and this increases according to the extent of the medium through which the light passes. Analogy, therefore, justifies the conclusion that there is no transparent medium which, if sufficiently extensive, would not absorb all the light which passes into it.

A very thin plate of glass is almost perfectly transparent, a thicker is less so, and according as the thickness is increased the transparency will be diminished. The distinctness with which objects are seen through the air diminishes as their distance increases, because more or less of the light transmitted from them is absorbed in its progress through the atmosphere. This is the case with the sun, moon, and other celestial objects, which when seen near the horizon are more dim, however clear the atmosphere may be, than when seen in the zenith. In the former case, the light transmitted from them passes through a greater mass of atmosphere, and more of it is absorbed. According to Bouguer, sea-water at about the depth of 700 feet would lose all its transparency, and the atmosphere would be impervious to the sun's light if it had a depth of 700 miles.

The transparency of the same substance varies according to the density of its structure, the transparency generally increasing with the density. Thus, charcoal is opaque, but if the same charcoal be converted into a diamond, which it may be, without any change of the matter of which it is composed, it will become transparent.

Bodies are said to be imperfectly transparent, or semi-transparent, when light passes through them so imperfectly, that the forms and colours of the objects behind them cannot be distinguished. Ground glass, paper, and thin tissues in general, foggy air, the clouds, horn, and various species of shell, such as tortoise-shell, are examples of this.

The degrees of this imperfect transparency are infinitely various, some substances, such as horn, being so nearly transparent as to render the form of a luminous object behind it indistinctly visible. Porous bodies, which are imperfectly transparent, usually have their transparency increased by filling their pores with some transparent liquid. Thus paper, which is imperfectly transparent, is rendered much more transparent by saturating it with oil, or by wetting it with any liquid. The variety of opal called hydrophane is white and opaque when dry, but when saturated with water it becomes transparent. Ground glass is rendered more transparent by pouring oil upon it. Two plates of ground glass placed one upon the other are very imperfectly transparent; but if the space between them be filled with oil, and their external surfaces be rubbed with the same liquid, they will be rendered nearly transparent.

7. Bodies, however opaque, lose their perfect opacity when reduced to the form of extremely attenuated laminæ. Gold, one of the most dense of metals, is, in a state of ordinary thickness, perfectly opaque; but if it be reduced to the form of leaf-gold by the process of the gold-beater, and attached to a plate of glass, light will pass partially through it, and to an eye placed behind it, it will appear of a greenish colour. Other metals, when equally attenuated, show the same imperfect opacity.

8. When rays of light encounter the surface of an opaque body, they are arrested in their progress, such surfaces not being penetrable by them. A certain part of them, more or less according to the quality of the surface and the nature of the body, is absorbed, and the remaining part is driven back into the medium from which the rays proceed. This recoil of the rays from the surface on which they strike is called *reflection*, and the light thus returning into the same medium from which it had arrived, is said to be *reflected*.

The manner in which the light is reflected from such a surface varies according as the surface is polished or unpolished, and according to the degree to which it is polished.

If light fall upon a uniformly rough surface of an opaque body, each point of such surface becomes the focus of a pencil of reflected light, the rays of such pencil diverging equally in all directions from such focus.

The pencils which thus radiate from the various points are those which render the surface visible. If the light were not thus reflected indifferently in all directions from each point of the surface, the surface would not be visible, as it is from whatever point it may be viewed.

The light which is thus reflected from the various points upon the surface of any opaque body, has the colour which is commonly imputed to the body. The conditions, however, which determine the colour of bodies will be fully explained hereafter. For the present, it will be sufficient to establish the fact, that each point of the surface of an opaque body which is illuminated is an independent focus from which light radiates, having the colour proper to such point, by which light each such point is rendered visible.

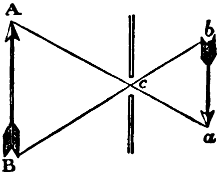
9. This mode of reflection, by which the forms and qualities of all external objects are rendered manifest to sight, has been generally denominated, though not as it should seem with strict propriety, the irregular reflection of light.

There is, nevertheless, nothing irregular in the character of the phenomena. The direction of the reflected rays is independent of each of the incident rays; but, nevertheless, such direction obeys the common law of radiation.

The existence of these radiant pencils proceeding from the surface of any illuminated object, and their independent propagation through the surrounding space, may be rendered still more manifest by the following experiment.

Let A B, fig. 1, be an illuminated object, placed before the window-shutter of a darkened room. Let *c* be a small hole made in the window-shutter, opposite the centre of the object. If a screen be held parallel to the window-shutter, and the object at some distance from the hole, an inverted picture of the object will be seen upon it, in which the form and colour of the object will be preserved; the magnitude, however, of such picture will vary according to the distance of the screen from the aperture. The less such distance, the less will be the magnitude of the picture.

Fig. 1.



Whether the object is luminous, as in fig. 2, or one which receives light from a luminary, as in fig. 3, the image will be equally produced and inverted, only it will be less brilliant in the

Fig. 2.

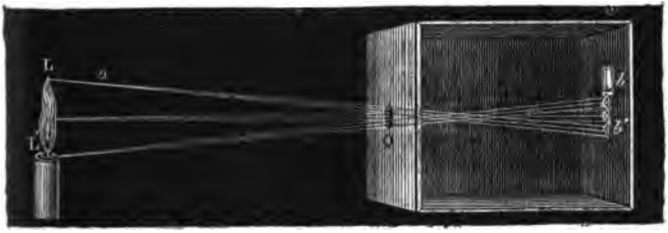
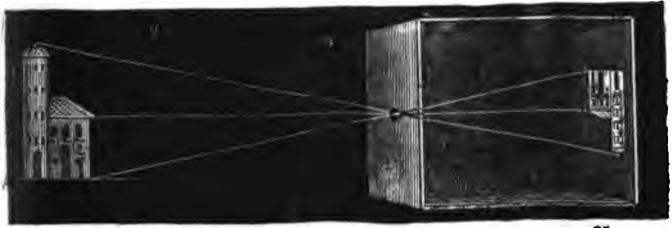


Fig. 3.



case of an object illuminated by another, as in fig. 3, than in that of a luminary, as in fig. 2.

This effect is easily explained. According to what has been already stated, each point of the surface of the illuminated object A B is a focus of a pencil of rays of light having the colour peculiar to such point. Thus, each portion of the pencil of rays which radiates from the point B, and has for its base the area of the aperture *c*, will pass through the aperture, and will continue its rectilinear course until it arrives at the point *b* upon the screen, where it will produce an illuminated point corresponding in colour to the point B.

In the same manner, the pencil diverging from A, and passing through the aperture *c*, will produce an illuminated point on the screen at *a*, corresponding in colour to the point A.

Each intermediate point of the object will produce a corresponding illuminated point on the screen. It is evident, therefore, that a series of illuminated points corresponding in arrangement and colour to those of the object will be formed upon the screen between *a* and *b*, their position, however, being inverted, the points which are highest in the object will be lowest in the picture.

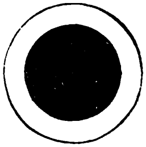
These effects may be witnessed in an interesting manner in any room which is exposed to a public thoroughfare frequented by moving objects. Let the window-shutters be closed and the interstices stopped so as to exclude all light except that which enters through any small hole in them, and if no hole be found in the shutters sufficiently small, a piece of paper or card may be pasted over any convenient aperture, and a hole of the required magnitude pierced in it. Coloured inverted images of all the objects passing before the window will thus be depicted on a screen conveniently placed. They will be exhibited on the opposite wall of the room; but unless the wall be white, the colours will not be distinctly perceptible. The smaller the hole admitting the light is, the more distinct but the less bright the pictures will be. As the hole is enlarged the brightness increases, but the distinctness diminishes. The want of distinctness arises from the spots of light on the screen, produced by each point of the object overlaying each other, so as to produce a confused effect.

10. Surfaces differ from each other in the proportion of light which they reflect and absorb. In general, the lighter the colour, other things being the same, the more light will be reflected and the less absorbed, and the darker the colour the less will be reflected and the more absorbed; but even the most intense black reflects some light. A surface of black velvet, or one blackened with lamp-black, are among the darkest known, yet each of these

reflects a certain quantity of rays. That they do so we perceive by the fact that they are visible. The eye recognises such surfaces as differing from a dark aperture not occupied by any material surface, and it can only thus recognise the appearance of the material surface by the light which it reflects. The following experiment, however, will render this more evident.

11. Blacken the inside of a tube, and fasten upon the extremity remote from the eye a plate of glass. To the centre of this plate of glass attach a circular opaque disk, somewhat less in diameter than the tube, so that in looking through the tube a transparent ring will be visible, as represented in fig. 4. In the centre of this transparent ring will appear an intensely dark circular space, being that occupied by the disk attached to the glass.

Fig. 4.



Now, let a piece of black velvet be held opposite the end of the tube, so as to be visible through the transparent ring. If the velvet reflected no light, then the transparent ring would become as dark as the disk in the centre; but that will not be the case. The velvet will appear by contrast with the disk, not black, but of a greyish colour, proving that a certain portion of light is reflected, which in this case is rendered perceptible by the removal of the brighter objects from the eye.

12. Irregular reflection, as it has been so improperly called, is one of the properties of light which is most essential to the efficiency of vision.

Without irregular reflection, light must be either absorbed by the surfaces on which it falls, or it must be regularly reflected. If the light which proceeds from luminous objects, natural or artificial, were absorbed by the surface of objects not luminous, then the only visible objects in the universe would be the sun, the stars, and artificial lights, such as flames.

These luminaries would, however, render nothing visible but themselves.

If the light radiating from luminous objects were only reflected regularly from the surface of non-luminous objects, these latter would still be invisible. They would have the effect of so many mirrors, in which the images of the luminous objects only could be seen. Thus, in the day-time, the image of the sun would be reflected from the surface of all objects around us, as if they were composed of looking-glass, but the objects themselves would be invisible. The moon would be as though it were a spherical mirror, in which the image of the sun only would be seen. A room in which artificial lights were placed would reflect these lights from the walls and other objects around as if they were specula, and all that would be visible would be the multiplied reflections of the artificial lights.

Irregular reflection, then, alone renders the forms and qualities of objects visible. It is not, however, merely by the first irregular reflection of light proceeding from luminaries by which this is effected. Objects illuminated and reflecting irregularly the light from their surfaces, become themselves, so to speak, secondary luminaries, by which other objects not within the direct influence of any luminary, are enlightened, and these in their turn reflecting light irregularly from their surfaces, illuminate others, which again perform the same part to another series of objects. Thus light is reverberated from object to object through an infinite series of reflections, so as to render innumerable objects visible which are altogether removed from the direct influence of any natural or artificial source of light.

13. The globe of the earth is surrounded with a mass of atmosphere extending forty or fifty miles above the surface.

The mass of air which thus envelopes the hemisphere of the earth presented towards the sun, is strongly illuminated by the solar light, and, like all other bodies, reflects irregularly this light. Each particle of air thus becomes a luminous centre, from which light radiates in every direction. In this manner, the atmosphere diffuses in all directions the light of the sun by irregular reflection. Were it not for this, the sun's light could only penetrate those spaces which are directly accessible to his rays. Thus, the sun shining upon the window of an apartment would illuminate just so much of that apartment as would be exposed to his direct rays, the rest remaining in darkness. But we find, on the contrary, that although that part of the room upon which the sun directly shines is more brilliantly illuminated than the surrounding parts, these latter are nevertheless strongly illuminated. All this light proceeds from the irregular reflection of the mass of atmosphere just mentioned.

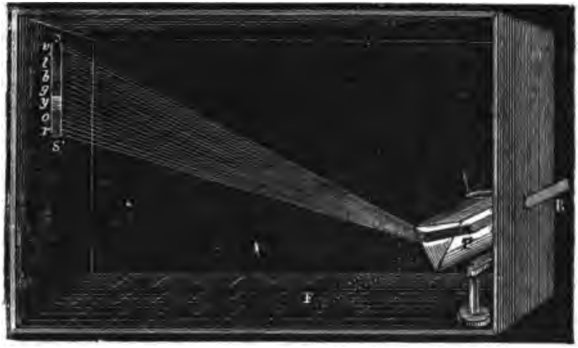


Fig. 7.—NEWTON'S CELEBRATED EXPERIMENT SHOWING THE DECOMPOSITION OF LIGHT.

COMMON THINGS.

COLOUR.

CHAPTER II.

14. Diffusion of light by all visible objects.—15. Decomposition of light by visible objects.—16. Experimental proof of the composition of light.—17. The prismatic spectrum.—18. The composition of solar light—19. The recomposition of light by prism and concave reflector.—20. The same by prism and lens.—21. The same with artificial colours.—22. Light of the same colour may have different refrangibilities.—23. Colours produced by combining different rays of the spectrum.—24. Complementary colours.—25. Colours of natural bodies generally compound.—26. Method of observing the spectrum by direct vision.—27. Why objects seen through prism are fringed with colours.—28. The prismatic colours, not all simple.—29. Sir D. Brewster's analysis of the spectrum.

14. But the solar light is further diffused by being again irregularly reflected from the surface of all the natural objects upon which it falls. The light thus irregularly reflected from the air falling upon all natural objects, is again reciprocally reflected from one to another of these through an indefinite series of multiplied reflections, so as to produce that diffused and general illumination which is necessary for the purposes of vision.

Light and shade are relative terms, signifying only different degrees of illumination. There is no shade so dark into which some light does not penetrate.

It is the same with artificial lights. A lamp placed in a room illuminates directly all those objects accessible to its rays. These objects reflect irregularly the light incident upon them, and illuminate thus more faintly others which are removed from the direct influence of the lamp, and thus, these again reflecting the light, illuminate a third series still more faintly; and so on. When it is desired to diffuse uniformly by reflection the light which radiates from a luminary, the object is often more effectually attained by means of an unpolished opaque reflector than by a polished one. White paper or card answers this purpose very effectually. Shades formed into conical surfaces placed over lamps are thus found to diffuse by reflection the light in particular directions, as in the case of billiard-tables or dinner-tables, where a uniformly diffused light is required. A polished reflector, in a like case, is found to diffuse light much more unequally.

In case of white paper or card, each point becomes a centre of radiation, and a general and uniform illumination is the consequence. The light obtained by reflection in such cases is always augmented by rendering the reflector perfectly opaque; for if it be in any degree transparent, as is sometimes the case with paper shades put over lamps, the light which passes through them is necessarily subtracted from that which is reflected.

15. We have stated that the colour of objects is that of the light which they reflect. It may then be asked how it happens that objects illuminated by the white light of the sun are not all white instead of having the infinitely various tints of colour by which they are characterised. The answer is, that the white light of the sun itself is a composition of all these various hues; that some objects reflect only the component lights of particular tints, and others those of other tints; that, in fact, the solar light falling on an object is generally decomposed, a part of it being absorbed by, or transmitted through, the object, and a part only reflected, and the object appears to have the colour peculiar to this latter part.

16. That solar light is actually a compound of lights of various tints was established by Newton by means of a memorable and beautiful experiment.

Let a ray of solar light be admitted through a small hole, P (fig. 5.) in a screen or partition S T, all other light being excluded from the space into which the pencil enters. If a white screen X Z be placed parallel to S T, and at a distance from it of about 12 feet, a circular spot of light nearly equal in diameter to the hole will appear upon it at P′, the point where the direction of the pencil meets the screen. Now let a glass prism, such as is shown in fig. 6, be placed at A B C, with the edge of its refracting angle B in a horizontal direction, and presented downwards so as to receive the pencil upon its side A B at Q. According to a well known principle in optics, the pencil would be refracted, in passing through the surface A B, in the direction Q L towards the perpendicular; and it would be again refracted, in emerging from the surface C B, from the perpendicular in the direction L K. It might therefore be expected that the effect of the prism would be merely to move the spot of light from P′ to some point, such as K, more elevated upon the screen. The phenomenon, however, will be very different. Instead of a spot of light, the screen will present an oblong coloured space, the outline of which is represented at M N as it would appear when viewed in front of the screen. A perspective view of the arrangement for making this celebrated experiment is given in fig. 7, p. 65.

Fig. 5.

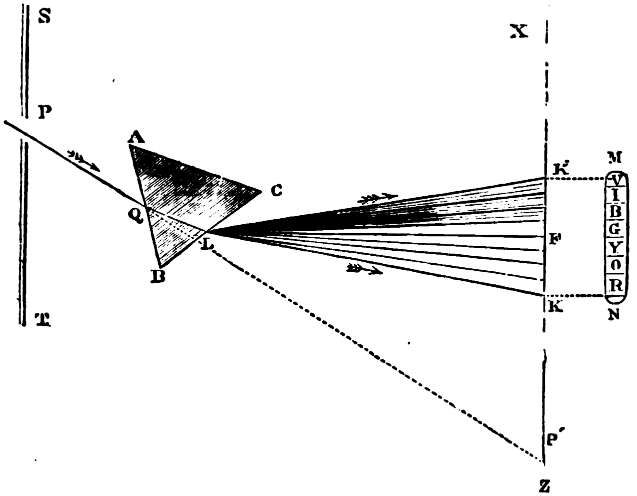
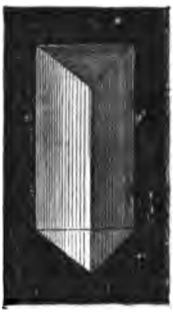


Fig. 6.



17. The sides of this oblong figure are parallel, straight, and vertical. Its ends are semi-circular, and its length consists of

a series of seven spaces, vividly coloured, the lowest space being red, R; the next in ascending, orange, O; and the succeeding spaces, yellow, Y; green, G; light blue, B; dark blue or indigo, I; and, in fine, violet, V.

These several coloured spaces are neither equal in magnitude nor uniform in colour. The red space R, commencing at the lowest point with a faint red, increases in brilliancy and intensity upwards. The red, losing its intensity, gradually melts into the orange, so that there is no definite line indicating where the red ends and the orange begins. In the same manner, the orange, attaining its greatest intensity near the middle of the space, gradually melts into the yellow; and in the same manner, each of the succeeding colours, having their greatest intensities near the middle of the spaces, melts towards its extremities into the adjacent colours.

The proportion of the whole length occupied by each space will depend upon the sort of glass of which the prism is composed. If it be flint-glass, and the entire length M N be supposed to consist of 360 equal parts, the following will be the length of each succeeding colour, commencing from the red upwards.

Red	56
Orange	27
Yellow	27
Green	46
Blue	48
Indigo	47
Violet	109
	360

It appears, therefore, that the ray of light P Q, after passing through the prism, is not only deflected from its original course P Q P′, but it is resolved into an infinite number of separate rays of light which diverge in a fan-like form, the extreme rays being L K and L K′, the former being directed to the lowest point of the coloured space upon the screen, and the latter to the highest point. The coloured space thus formed upon the screen is called the *prismatic spectrum.*

18. From this experiment the following consequences are inferred:—

1°. Solar light is a compound principle, composed of several parts differing from each other in their properties.

2°. The several parts composing solar light differ from each other in refrangibility, those rays which are directed to the lowest part of the spectrum being the least refrangible, and those directed to the highest part being the most refrangible; the rays directed to the intermediate parts having intermediate degrees of refrangibility.

3°. Rays which are differently refrangible are also differently coloured.

4°. The least refrangible rays composing solar light are the red rays, which compose the lowest division R of the spectrum. But these red rays are not all equally refrangible, nor are they precisely of the same colour. The most refrangible red rays are those which are deflected to the lowest point of the red space R, and the least refrangible are those which are directed to the point where the red melts into the orange. Between these there are an infinite number of red rays having intermediate degrees of refrangibility. The colour of the red rays varies with their refrangibility, the most intense red being that of rays whose refrangibility is intermediate between those of the extreme rays of the red space.

The same observations will be applicable to rays of all the other colours.

5°. Each of these components of solar light having a different refrangibility will have for each transparent substance a different index of refraction. Thus the index of refraction of the red rays will be less than the index of refraction of the orange rays, and that of these latter will be less than the index of refraction of the yellow rays, and so on; the index of refraction of violet rays being greater than for any other colour.

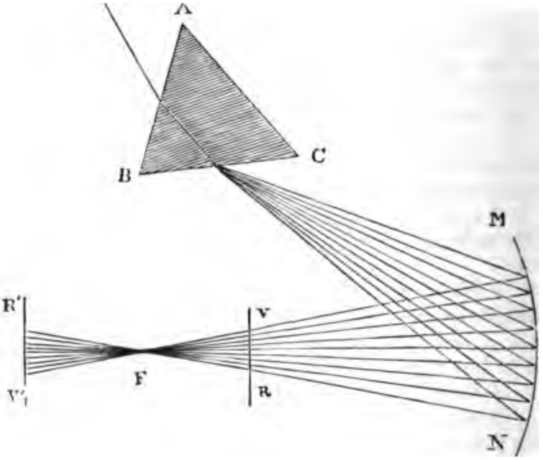
But the rays of each colour being themselves differently refrangible, according as they fall on different parts of the coloured space, they will, strictly speaking, have different indices of refraction. The index of refraction, therefore, of any particular colour must be understood as expressing the index of refraction of the middle or mean ray of that particular colour. Thus, the index of refraction of the red rays will be the index of refraction of the middle ray of the red space; the index of refraction of the orange rays will be the index of refraction of the middle ray of the orange space; and so on.

It must not, however, be supposed that a pencil of solar light consists of separate and distinct rays of different colours which form the spectrum, so that it might be possible by any mechanical division of such a pencil to resolve it into such rays. Each individual ray of such a pencil is composed of all the rays of the spectrum, just as the gases oxygen and hydrogen, which are the chemical constituents of water, enter into the composition of each particle of that liquid, no matter how minute it be.

19. As the solar light is resolved by the prism into the various

coloured lights exhibited in the spectrum, it might be expected that, these coloured lights being mixed together in the proportion in which they are found in the spectrum, white light would be reproduced. This is accordingly found to be the case. If the spectrum formed by the prism A B C (fig. 8.) instead of being thrown upon a screen, be received upon a concave reflector M N, the rays which diverged from the prism and formed the spectrum will be reflected converging to the focus F; and after intersecting each other at that point, they will again diverge, the ray R F passing in the direction F R′, and V F in the direction F V′.

Fig. 8.



Now, if a screen be held between F and the reflector, the spectrum will be seen upon the screen. If the screen be then moved from the reflector towards the focus F, the spectrum upon the screen will gradually diminish in length, the extreme colours R and V approaching each other. When it comes so near to F that the extreme limits of the red and violet touch each other, the central point of the spectrum will become white; and when the screen arrives at the point F, the coloured rays being all mingled together, the spectrum will be reduced to a white colourless spot.

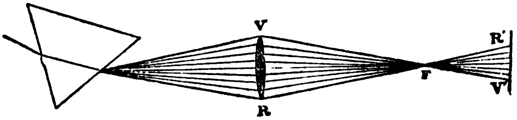
Just before the screen arrives at F, it will present the appearance of a white spot, fringed at the top with the colours forming the upper end of the spectrum, violet, blue, and green, and at the bottom with those forming the lower end of the spectrum, red, orange, and yellow. This effect is explained by the fact, that until the screen is brought to the focus F, the extreme rays at the other end of the spectrum are not combined with the other colours.

If the screen be removed beyond F, the same succession of appearances will be produced upon it as were exhibited in its approach to F, but the colours will be shown in a reversed position.

As the screen leaves F, the white spot upon it is fringed as before, but the upper fringe is composed of red, orange, and yellow, while the lower is composed of violet, blue, and green; and when the screen is removed so far from the focus F as to prevent the superposition of the colours, the spectrum will be produced upon it, with the red at the top, and the violet at the bottom, the position being inverted with respect to that which the screen exhibited at the other side of the focus. These circumstances are all explained by the fact that the rays converging to F intersect each other there.

20. Similar effects may be produced by receiving the spectrum upon a double convex lens, as represented in fig. 9. The rays are made as before to converge to a focus F, where a white spot would be produced upon the screen. Before the screen arrives at F, and after it passes it, the same effects will be produced as with the concave reflector.

Fig. 9.

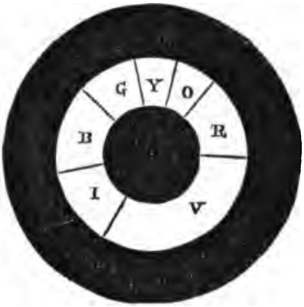


21. The proposition, that the combination of colours exhibited in the prismatic spectrum produces whiteness, may be further verified by the following experiment:—

Let a circular card be framed with a blackened circle, and its centre surrounded by a white circular band, and a black external border, as represented in fig. 11.

Let the white circular band be divided into seven spaces proportional in magnitude to the spaces occupied by the seven colours in the prismatic spectrum, these spaces being R, O, Y, G, B, I, and V. Let these spaces be respectively coloured with artificial colours resembling as near as practicable in their tints the colours of the spectrum. If the centre of this card be placed upon a spindle, and a very rapid motion of rotation be imparted to it, the ring on which the seven colours are painted will present the appearance of a greyish white. In this case, if all the colours except one were covered with black, the revolving card would present the appearance of a continuous ring of that colour; and, consequently, if all the coloured spaces be uncovered, seven continuous rings of the several colours would be produced; but these rings being superposed and mingled together will produce the same effect on the sight as if all the seven colours were mixed together in the proportion which they occupy on the card. If the colours were as intense and as pure as they are in the spectrum, the revolving card would exhibit a perfectly white ring; but as the colours of natural bodies are never perfectly pure, the colour produced in this case is greyish.

Fig. 11.



This experiment may be further varied by leaving uncovered any two, three, or more combinations of the colours depicted on the card. In such case the rotation of the card produces the appearance of a ring of that colour which would result from the mixture of the colours left uncovered; thus, if the red and yellow spaces remain uncovered, the card will produce the appearance of an orange ring; if the yellow and blue remain uncovered, it will produce the appearance of a green ring; and so on.

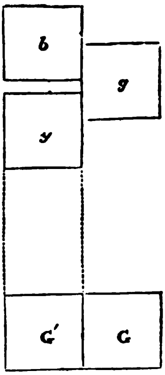
The following pretty experiment, illustrating the recomposition of light, was suggested by Newton.

The spectrum is received upon seven plane reflectors, as shown in fig. 10, p. 57, which are so suspended as to be capable of shifting their planes at pleasure. They are so adjusted as to receive the light proceeding from the prism, which correspond to the seven different colours, and to reflect it to the same point upon a screen conveniently placed, or upon the ceiling of the room. The spot of light thus produced will be white.

22. Although the phenomena attending the prismatic spectrum prove that rays of light which differ in refrangibility also differ in colour, the converse of this proposition must not be inferred; for it is easy to show that two lights which are of precisely the same colour, may suffer very different effects when transmitted through a prism.

Let us suppose two holes made in the screen on which the spectrum is thrown in the middle of the space occupied by the blue and yellow colours, so that rays of these colours may be transmitted through the holes. Let these rays be received upon a double convex lens, and brought to a focus at G′, (fig. 12) upon a sheet of white paper, so as to illuminate the spot G′. The colour that it produces then will be a green. Let another spectrum be now thrown by a prism upon the screen, and let a hole be made in the screen at that part of the green space where the tint is precisely similar to the colour produced at G′ on the white paper, and let the light which passes through this hole fall upon the spot G beyond G′.

Fig. 12.



The spaces G and G′ will then be illuminated by lights of precisely the same colour; but it will be easy to show that these lights are not similarly refrangible.

Let them be viewed through a prism having its refracting angle presented upwards. The image of the illuminated space G will be seen in a more elevated position at *g*; but two images will be produced of the space G′, one yellow and the other blue at *y* and *b*, the yellow image *y* being a little below *g*, and the blue image *b* a little above it. Thus it is evident that the green light on the space G′ is a compound of yellow and blue, and is separable into its constituents by refraction, while the similar green light on the space G is incapable of decomposition by refraction.

23. An endless variety of tints may be produced by combining in various ways the colours composing the prismatic spectrum; indeed, there is no colour whatever which may not be produced by some combination of these tints. Thus, all the shades of red may be produced by combining some proportion of the yellow and orange with the prismatic red; all the shades of orange may be produced by combining more or less of the red and yellow with each other and with the orange; all the shades of yellow may

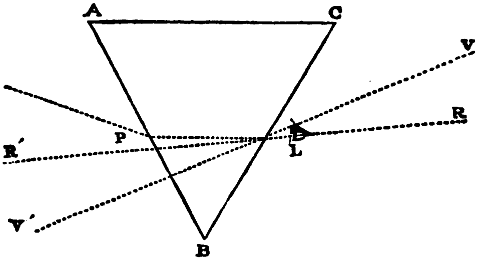
be produced by varying the proportion of green, yellow, and orange; and so on.

24. If two tints T and T′ be produced, the former T by combining a certain number of prismatic colours, and the latter T′ by combining the remainder together, these two tints T and T′ are called *complementary*, because each of these contains just those colours which the other wants to produce complete whiteness; and, consequently, if the two be mixed together, whiteness will be the result. Thus, a colour produced by the combination of the red, orange, yellow, and green of the spectrum in their just proportions, will be complementary to another colour produced by the blue, indigo, and violet in their just proportions, and these two colours, if mixed together, would produce whiteness.

25. Almost all colours, natural or artificial, except those of the prismatic spectrum itself, are more or less compounded, and their combined character belongs to them equally when they have tints identical with the coloured spaces of the spectrum. Thus, a natural object whose colour is indistinguishable from the yellow space of the spectrum, will be found, when subjected to the action of the prism, to refract light in which there is more or less of green or orange; and an object which appears blue will be found to have in its colour more or less of green and violet.

26. Instead of receiving the spectrum on a screen, it may be viewed directly by placing the eye behind the prism A B C, fig. 13 at L, so as to receive the light as it emerges. This mode of observing the prismatic effects is in many cases more convenient than by means of the screen, colours being thus rendered observable which would be too feeble to be visible after reflection from the surface of the screen. It is necessary, however, to consider that in this manner of viewing the prismatic phenomena, the colours will be seen in an order the reverse of that which they would hold on the screen; for if the eye be placed at L, it will

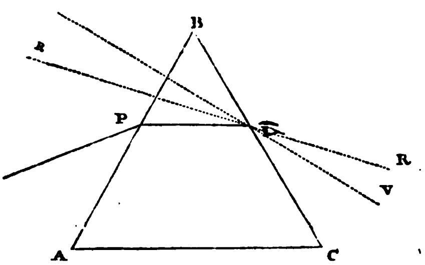
Fig. 13.



receive the violet ray which enters in the direction L V as if such ray had proceeded from V′, and it will receive the red ray which enters it in the direction R as if it had proceeded from R′; the red will therefore appear at the top, and the violet at the bottom of the spectrum, when the refracting angle B of the prism is turned downwards.

But if the refracting angle B be turned upwards, as represented in fig. 14, then the red will appear at the bottom, and the violet at the top of the spectrum, as will be perceived from the figure.

Fig. 14.



27. In general, when objects are viewed through a prism they appear with their proper colours, except at their boundaries, where they are fringed with the prismatic tints in directions parallel to the edge of the refracting angle of the prism.

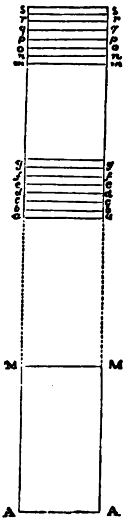
Let A A M M, (fig. 15,) be a small rectangular object seen upon a black ground, the sides A M being vertical, and A A and M M horizontal. Let us first suppose that this object has the colour of a pure homogeneous red. If this object be viewed through a prism whose refracting angle is directed upwards with its edge horizontal, it will be seen in a more elevated position, such as *a a m m*, as already explained.

Let us next suppose that the object A A M M has the colour of a pure homogeneous orange. When viewed through the prism it will, as already explained, appear in a position *b b n n*, a little above *a a m m*.

If we next suppose the object A A M M to be coloured with homogeneous yellow, it will be raised by the prism to *c c o o*, a little above the orange image.

If it be next supposed to have the colour of a prismatic green, it will be seen at *d d p p*, a little above the yellow image; and if it be coloured light blue, its image will be seen at *e e q q*, above the green image; if it be dark blue or indigo, its image will be in the position *f f r r;* if it be violet, its image will be in the position *g g s s.*

Fig. 15.



Now, if we suppose the object A A M M to be white, that is to say, to have a colour which combines all the prismatic colours together, then all these several images will be seen at once through the prism in the respective positions already described. They will therefore be more or less superposed one upon the other, and the image will exhibit in its different parts those tints which correspond to the mixture of the colours thus superposed.

Hence it appears that the space between *a a* and *b b* from which all colour except the red is excluded, will appear red; in the space between *b b* and *c c*, in which the orange image is superposed upon the red image, a colour will be exhibited corresponding to the mixture of these two colours; in the space between *c c* and *d d*, the three images red, orange, and yellow are superposed, and a colour corresponding to the combination of these will be produced. In fine, the colours which are superposed between every successive division of the upper and lower edges of the combined images are as follows, where the prismatic colours are designated by the capital letters, and their mixture or superposition by the sign +:

Between *a a* and *b b*	R
„ *b b* „ *c c*	R + O
„ *c c* „ *d d*	R + O + Y
„ *d d* „ *e e*	R + O + Y + G
„ *e e* „ *f f*	R + O + Y + G + B
„ *f f* „ *g g*	R + O + Y + G + B + I
„ *g g* „ *m m*	R + O + Y + G + B + I + V = W.

Thus it appears that the space between *g g* the bottom of the violet image and the top *m m* of the red image is coloured with a white light, because in this space all the seven images are superposed.

In the space between *g g*, the bottom of the violet image, and *f f*, the bottom of the dark blue image, there is a space which is illuminated by all the prismatic colours except the violet, and this space consequently approaches so near a white as to be scarcely distinguishable from it. The space between *f f*, the bottom of the dark blue image, and *e e*, the bottom of the light blue image, is illuminated by all the colours except the dark blue and indigo, and it consequently has a yellowish tint. The succeeding divisions downwards towards *a a* become more and more red until they attain the pure prismatic red of the lowest division. The colours of the upper extremity of the image may in like manner be shown to be as follows.

Between *s s* and *r r*	V
,, *r r* ,, *q q*	V + I
,, *q q* ,, *p p*	V + I + B
,, *p p* ,, *o o*	V + I + B + G
,, *o o* ,, *n n*	V + I + B + G + Y
,, *n n* ,, *m m*	V + I + B + G + Y + O
,, *m m* ,, *g g*	V + I + B + G + Y + O + R = W.

Thus it appears that the highest fringe at the upper edge is violet, that those which succeed it are formed by the mixture of violet and blue, to which green and yellow are successively added, until the colours become so completely combined that the fringe is scarcely distinguishable from a pure white. It is evident, therefore, that at the lower extremity the reds, and at the upper the blues, prevail.

If the object A A M M viewed through the prism be not white, then the preceding conclusions must be modified according to the analysis of its colour. Thus, if its colour be a green, it may be either a pure homogeneous green, or one formed by the combination of blue and yellow or other prismatic tints. In the former case, the prism will exhibit the object without fringes, but in the latter it will be fringed according to the composition of its colour, determined by the same principles as those which have been applied to the object A A M M.

28. In all that precedes it has been assumed that the light composing each part of the prismatic spectrum is simple and homogeneous. This conclusion, deduced by Newton, and adopted generally by all physical investigators since his time, is based on the assumption, that light which, being refracted by transparent media, cannot be resolved into parts differently refrangible, is simple and homogeneous.

Sir David Brewster, has, however, published the results of a series of observations, from which it would follow, that a pencil of light which does not consist of parts differently refrangible, may, nevertheless, be resolved into parts which have different colours; in other words that the light of certain parts of the spectrum, such, for example, as orange and green, although simple so far as respects refraction, is compound so far as respects colour. Thus, the orange light may be resolved into two lights equally refrangible, but differing in colour, one being red and the other yellow; and the green light may in like manner be resolved into two equally refrangible, one being yellow and the other blue.

29. In a word, the observations and experiments of Sir David Brewster have led him to the conclusion that the prismatic spectrum consists in reality of three spectra of nearly equal length, each of uniform colour, superposed one upon another; and that the colours which the actual spectrum exhibit arise from the mixture of the uniform colours of these three spectra superposed. The colours of these three elementary spectra, according to Sir David Brewster, are red, yellow, and blue. He shows that by the combination of these three, not only all the colours exhibited in the prismatic spectrum may be reproduced, but that their combination also produces white light. He contends, therefore, that the white light of the sun consists not of seven, but of three constituent lights, red, yellow, and blue.

This conclusion is established by showing that there is another method by which light may be resolved into its components, besides the method of refraction by prisms. In passing through certain coloured media, it is admitted that a portion of the light incident is intercepted at the surface upon which it is incident, and in its passage through the medium a part only is transmitted.

Now, this property of colours is taken by Sir David Brewster as another method, independently of refraction, of decomposing colours. He assumes that such a medium resolves the light incident upon it into two parts; first, the part which it transmits; and, secondly, the part which it intercepts. He concludes that these two parts are complementary, that is to say, that each contains what the other wants to make up white solar light; or, more generally, that the incident light, whatever be its nature, must be assumed to be a compound, consisting of the light transmitted and the light intercepted.

This being assumed, let a coloured medium, such as a plate of blue glass, be held between the eye and the spectrum. Certain colours of the spectrum will be transmitted and others intercepted. If the colours of the spectrum be simple and homogeneous light, such as they are assumed to be in the Newtonian theory of the decomposition of light, then the consequence would be that the appearance of the spectrum seen through the coloured medium would consist of dark and coloured spots; those simple lights intercepted by the glass appearing dark, and those transmitted by the glass having their proper colour. For if each colour of the prism be, as is assumed in the chromatic theory, simple, then the plate of glass can make no change in its colour by transmission.

It must therefore be wholly transmitted, partly transmitted, or wholly intercepted. If it be wholly transmitted, no change will be made, therefore, in its colour or intensity; if it be partly transmitted, its colour will remain the same, but its intensity will be diminished; if it be wholly intercepted, the space it occupied on the spectrum will be black. But these are not the effects, as Sir David Brewster states, which are observed. He finds, on the other hand, that the coloured spaces on the spectrum are not merely diminished in intensity, but actually changed in colour. Now, if any space of the spectrum be changed in colour, it follows from what has been stated, that the light transmitted must be a constituent of the colour of that space, to which the light intercepted being added, they would reproduce the colour of the spectrum. By such an experiment as this, Sir David Brewster found that the parts of the spectrum occupied by the orange and green lights produced yellow, from which he inferred that the glass intercepted the red, which combined with the yellow produced orange, and the blue, which combined with the yellow produced green. But if the glass have the power of thus intercepting the red and blue light, it might be expected that the red and the blue spaces of the spectrum would appear dark. He accordingly found that the light of the middle of the red space was almost entirely absorbed, as was also a considerable part of the blue space.

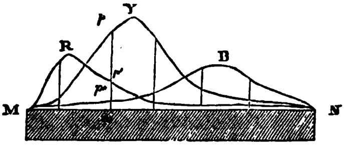
From experiments like these, which he made in great number, and under various conditions, Sir David Brewster deduced the conclusion to which we have adverted above.

He inferred that at a point of the spectrum, red, yellow, and blue light are combined in various proportions, the colour of each part being determined by the proportional intensities of these three colours in the mixture. In the red space, the proportions of blue and yellow are exactly those necessary to produce white light, but the red is in excess; a portion of it combined with the blue and yellow produces a white light, which is reddened by the surplusage of red. In the same manner, in the yellow space, the proportion of blue and red is that which is proper to white light, but there is a greater than the just proportion of yellow.

A part of this combining with the blue and red produces white light, which is rendered yellow by the surprus. In the same manner exactly, the blue space is shown to consist of a surplusage of blue, combined with the proportion of red and yellow, and the remainder of the blue necessary for whiteness. The other colours of the spectrum, according to Sir David Brewster, are secondary, or the result of combinations of red, yellow, and blue.

The means by which these three primary colours produce the tints of the spectrum may be more clearly understood by reference to fig. 16, wherein M N represents the prismatic spectrum with its usual tints. The curve M R N represents the varying intensity of the red spectrum, M Y N that of the yellow, and M B N that of the blue spectrum. The distance of each part of these curves respectively from M N is understood to be proportional to the intensity of the colour of that part, and the relative lengths of the perpendicular included within each curve represents the proportion of the intensities of the combined colours. Thus, at the point p, the three colours are mixed in the proportion of the lengths of the perpendiculars $p\ n$, $p'\ n$, $p''\ n$, the first representing the proportion of yellow, the second red, and the third blue; the red and yellow predominating, the colour at this point will be orange.

Fig. 16.



These observations and experiments, and the conclusions deduced from them by Sir David Brewster, have been now before the scientific world for more than twenty years. The experiments do not appear to have been repeated, nor the chromatic doctrine inferred from them to have been yet generally assented to or adopted. The chromatic analysis of Newton is the only theory advanced by physical authors.

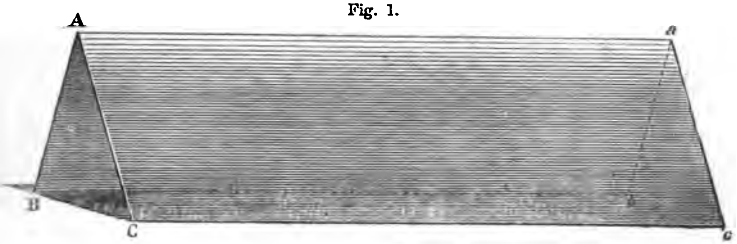
THE KALEIDOSCOPE.

1. Origin of the name.—2. Structure of the instrument.—3. Its optical effect.—4. Varieties of its form.—5. Its occasional use in the arts.—6. Another optical toy depending on two reflections.

1. THIS pretty optical toy, which is named from three Greek words, *καλον ειδος* (Kalon eidos), *a beautiful form*, and *σκοπεω* (skopeo) *I see*, depends upon the properties of the looking-glass.

2. Two oblong slips of looking-glass, A a c C, and A a b B, fig. 1, are placed edge to edge at A a, inclined to each other at an angle of 60°.

Fig. 1.

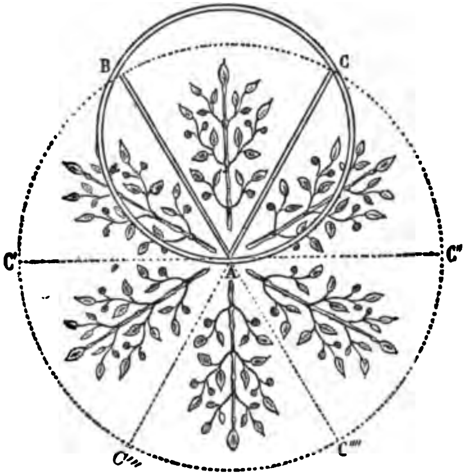


Thus placed, they are fixed in a tube of tin or brass of corresponding size, one end view of which is shown in fig. 2, where the circle A C B represents the tube, and A B and A C the edges of the plates of glass. One end of the tube is covered by two discs of glass, between which broken pieces of coloured glass or other transparent coloured object are placed loosely, so that they can fall from side to side, and take an infinite variety of casual arrangements. The external disc is ground-glass, to prevent the view of external objects disturbing the effect. The other end of the tube is covered by a diaphragm, with a small eye-hole in its centre, through which the observer looks at the coloured objects contained in the cell at the other end. He not only sees these objects, but also their reflection in each of the inclined glasses; and when the angle of inclination is 60°, the object will be seen five times repeated in positions regularly disposed round the line formed by the edges at which the glasses touch each other.

3. The angular space, B A C, included between the glasses, and every object within it, will be seen reflected in each glass. Thus B A C will be seen in the glass B A, as if it were repeated in the

space B A C′, and in the glass A C, as if it were repeated in the space C A C″. But this is not all. The reflection B A C′ becomes an object before the glass A C, and being reflected by it, is reproduced in the space C″ A C⁗, and the reflection C A C″ being reflected by the glass A B, is reproduced in the space C′ A C‴. Thus besides

Fig. 2.



the view of the objects themselves which are between the glasses, and which would be seen if there were no reflection, the observer will see the four reflections, two C A C″ and C″ A C⁗ to the right, and two B A C′ and C′ A C‴ to the left.

But the reflection C′ A C‴ is again reflected by the glass A C, and is seen in the space C‴ A C⁗, and at the same time the reflection C″ A C⁗ is reflected in the glass A B, and is also reproduced in the same space C″ A C.″″ Thus it appears that this space C″ A C⁗ receives the reflection of both glasses.

The observer looking through the eye-hole of the kaleidoscope sees a circle whose apparent diameter C C‴ is twice A C the breadth of the reflector. This circle is divided into six angular spaces, two of which are the first reflections, and other two the second reflections of the inclined glasses. The other two consist of the actual space included between the glasses, and a similar space opposite to it which receives at once the third reflection of both glasses.

Since looking-glasses never reflect *all* the light incident upon them, these reflections will not be as vivid as the direct view of the space B C; nor will they, compared one with another, be equally vivid. The reflections B C' and C' C'' will be less vivid than the object B C, but more so than the second reflections C' C''' and C'' C''''. The third reflection C''' C'''' would be less vivid than the second C' C''' and C'' C'''', if it proceeded only from one glass as do the latter. But it must be remembered that being the combined reflection of both glasses, the loss of brightness by the multiplied reflections of each glass is to some extent compensated.

4. We have here supposed that the glasses are inclined at 60°, but they may be inclined at any angle which is an aliquot part of 360°. Thus if they are inclined at 90°, the circular space or field of view round A will be divided into four angular parts, and the same observations are applicable. If the glasses are inclined at an angle of 45°, the field of view will be divided into eight equal angular spaces, seven of which will be filled by the reflections.

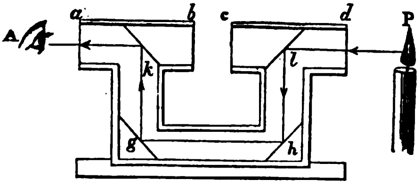
From what has been here explained, the unequal brightness of the angular spaces seen in the kaleidoscope will be understood. If, as is most common, the angle of the glasses be 60°, this is perceptible, but if it be 45°, the repeated reflections so reduce the brightness as to impair the beauty of the effect.

5. The effects of the kaleidoscope are very striking, in consequence of the endless variety of which they are susceptible, even with a single cell at the object end of the instrument; but it may be so arranged that several cells, including different collections of coloured objects, may be provided, and may be changed one for another, fitting on the end of the tube like the cover of the object glass of a telescope.

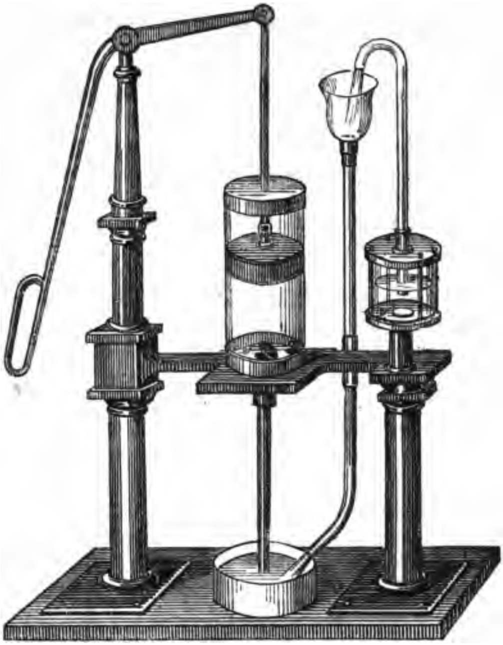
The effects of this pretty little optical contrivance have been occasionally rendered useful in the industrial arts, in suggesting patterns for carpets and other products of the loom.

6. An amusing optical toy is represented in fig. 3, by means of which objects may be seen, notwithstanding the interposition of any opaque screen between them and the eye. The rays proceeding from the object P entering the tube *d* strike on the mirror *l*

Fig. 3.



placed at an angle of 45°, and are reflected downwards vertically to the mirror *h*, also placed at 45°, from which they are reflected horizontally to the mirror *g* placed at 45°, from which they are again reflected vertically to the mirror *k* placed at 45°, from which they are reflected horizontally to the eye at A. The eye thus sees the object after four reflections, the rays which render it visible having travelled round the rectangular tube *l h g k*.



FORCING PUMP

COMMON THINGS.

◆

PUMPS.

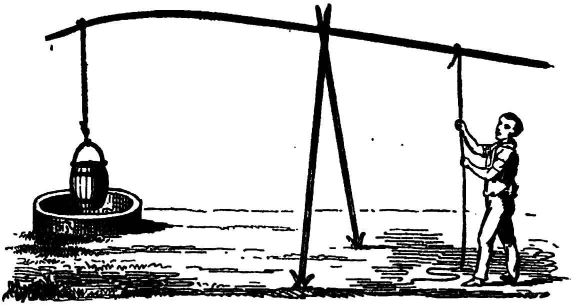
1. Earliest methods of raising water.—2. Bucket in a well.—3. By windlass and rope.—4. By two buckets balanced over a pulley.—5. Method of working these by animal power.—6. The rope in this case balances itself.—7. The lifting pump.—8. Double lifting pump worked by animal power.—9. Various forms of valves.—10. Clack valves.—11. Conical spindle valves.—12. Ball valves.—13. The suction pump.—14. Analysis of its action.—15. Forcing pump.—16. Same with air vessel.—17. Same with solid plunger.—18. Double action forcing pump.—19. Garden watering pumps.—20. Fire-engine.—21. Chain pump.—22. Drainage of mines.

1. As water is one of the most universal necessaries of life, and abundant as it is in nature, is not always found in the localities where circumstances oblige us to fix our habitations, expedients by which it can be obtained in sufficient quantity, and of the

necessary purity, have been among the earliest mechanical and physical inventions in every country. Natural springs showed that sources of water existed in the lower strata of the earth. This suggested the process of well-sinking or boring for water. But the water when thus found rarely rises to the surface spontaneously. It does so in those deep springs called artesian wells; but in all ordinary cases where a shaft has been sunk deep enough to find water, the water collects in the bottom of the shaft, and never rises above a certain level. Expedients are therefore necessary in all such cases to raise it to the surface.

2. The first and rudest of these contrivances, is to let down a bucket by means of a rope, and thus to draw up one bucket-full after another. The rope by which the bucket is elevated, when the well is not very deep, is sometimes attached to the long arm of a lever (fig. 1) the shorter arm being pulled down when the bucket is drawn up full. This is perhaps the rudest and most inartificial of all contrivances for the elevation of the water. A pulley established over the mouth of the well is one degree more efficient.

Fig. 1.



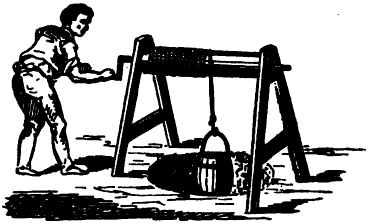
The bucket being let down and dipped in the water, is drawn up by pulling the rope.

In this case the labour is expended not only in raising the weight of the water and of the bucket which contains it, but also that of the rope, which, if the well be deep, is not inconsiderable. Besides this a certain force must be exerted to bend the rope continually over the groove of the pulley, and to overcome the friction of the pulley itself in moving upon its axle.

3. A windlass established over the mouth of the well (fig. 2) is one degree, and only one degree, more efficient than these rude

expedients. In this case the bucket is raised by turning the winch of the windlass, so that the rope is gradually wound upon its axle. The power has still to raise the weight of the rope, to produce its flexure on the axle, and to overcome the friction of the axle of the windlass in its bearings.

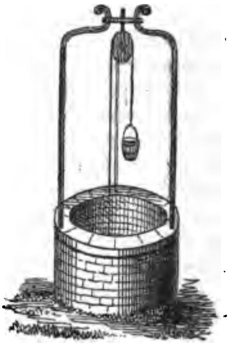
Fig. 2.



In the contrivance of mechanical agents, the first object is always to remove as much as possible all sources by which the moving power is absorbed upon useless objects. In the present case the only useful exertion of the moving force is that which is engaged in raising the water. The useless parts of the force expended, are, *first*, that absorbed by the weight of the bucket; *secondly*, that absorbed by the weight of the rope; *thirdly*, that absorbed in bending the rope over the groove of the pulley, or the curvature of the axle; *fourthly*, that which is expended on the friction of the axle in its bearings; *fifthly*, that which is expended in drawing the bucket aside when it has been elevated, and discharging the water from it into the vessel or reservoir destined to receive it; and, *sixthly*, that which is expended in letting down the bucket into the well to be refilled.

Now when all these sources of waste of power are considered and estimated, and their aggregate amount determined, it will be apparent that they greatly exceed the force expended upon the mere elevation of the water.

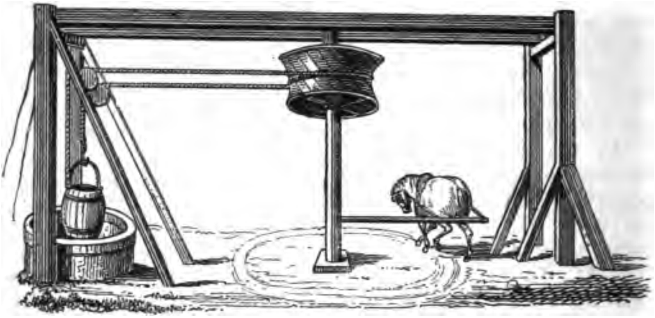
Fig. 3.



4. A part of the loss of power arising from these causes is sometimes removed by the simple expedient of attaching two buckets to the extremities of the rope which passes over the pulley (fig. 3) established above the well. By these means, while the full bucket is drawn up the empty one descends, and by its weight and that of the rope which descends with it, the weight of the full bucket and the rope which ascends with it is balanced, so that the power has only to act against the weight of the water, the friction and the resistance to flexure presented by the rope.

5. Animal power may be applied to this method of raising water by such an arrangement as is represented in fig. 4. This is

Fig. 4.



the method generally used in France by the market gardeners, in the environs of large towns, to raise water for irrigation. Two pulleys are established side by side, over the well, at such a distance asunder that two buckets or barrels suspended from them may pass each other as one ascends and the other descends, without mutual collision or obstruction. The rope supporting one bucket, after passing over one of these pulleys, is carried two or three times round a large vertical drum erected near the well, and then passing over the other pulley is let down into the well with the other bucket attached to it.

The semicircular handles to which the rope is attached, are connected with the barrels, not at the edge of the mouth, but at two points in their sides, a little above their middle point, so that when filled they will maintain themselves steadily in the vertical position, but when empty they will easily be turned upon their sides by mere contact with the surface of the water so as to fill themselves, when let down empty.

A horse or ox yoked to a lever of considerable length, projecting from the vertical shaft, turns it, and with it the drum, and continues to go round in the same direction, until one barrel is raised to the mouth of the well and the other is plunged in the water below and filled, the contents of this barrel being discharged into a reservoir or vessel destined to receive it. The animal is then yoked in the other direction, and again travels round until the other barrel is raised, and that which was just discharged let down.

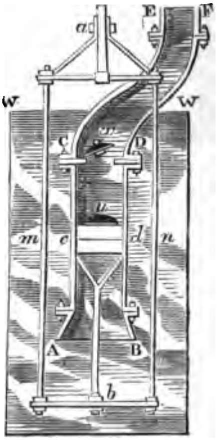
6. It is evident that in this and all similar arrangements the weight of the rope on the whole balances itself; for although it preponderates against the power when the full barrel begins to

ascend, the ascending part of the rope being then longer than the descending, this preponderance gradually decreases until the ascending meets the descending barrel. At this point, the ascending and descending parts of the rope being equal, balance each other, and after this the descending part, preponderating, aids the power just as much as the ascending part previously opposed it. There is, therefore, so far as relates to the weight of the rope, a perfect compensation.

The same apparatus is much used in France, in raising stone through vertical shafts from subterranean quarries, and other mining operations.

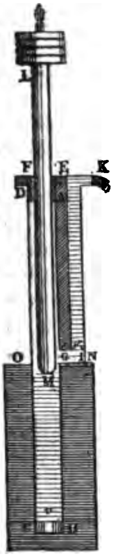
7. If, instead of a rope and bucket, a pipe or tube be let down into the well, and in this pipe a piston be provided, having a valve in it opening upwards, this piston being worked in the usual manner upwards and downwards, the water would be lifted in the pipe. Such an apparatus is called a lifting-pump, and is represented in fig. 5: W is the water, *c d* the piston, *u* the valve in it which opens upwards. When the piston is moved downwards, this valve opens, and the water passes through it. When the piston is moved upwards, the column of water is pushed up, and the valve is kept closed by the pressure of the water upon it. A valve *x* is placed at C D in a fixed position, through which the column of water passes when the piston rises, and which prevents the return of such water downwards, the valve being kept closed by the weight of the water above it. The column of water driven upwards by the piston is pushed to any required height, through the pipe E F. In such an apparatus, the moving power must be equal to the weight of the water raised, together with the weight of the pump-rod and frame by which the piston is worked, as well as the friction of the moving parts.

Fig. 5.



8. A very ingenious form of pump which, though differing altogether in appearance from the lifting pump, acts nevertheless upon precisely the same principle, is shown in fig. 6. It has the advantage of being nearly free from friction, and of being capable of being worked by the weight of an animal walking up an inclined plane, which is the most advantageous manner in which animal power can be applied.

Fig. 6.



Let D C be a wooden tube of any shape, round or square, which descends to a depth in the well or reservoir equal to the height above the surface of the reservoir to which the water is required to be raised. Thus if D O be the height to which the water is to be raised above the level of the well, then the depth O C must be at least equal to D O. L M is a heavy beam or plunger, suspended from a chain, and capable of descending by its own weight in water, and passing water-tight through the collar F E. A valve, *v*, covers an opening placed at the bottom of the tube. By the hydrostatic pressure the water will enter the valve *v*, and fill the barrel to the level O G of the water in the cistern. G I is a short tube proceeding from the side of the barrel, at the surface of the water, and communicating with the vertical tube E N by a valve I, which opens upwards. K is the spout of discharge. The plunger L M hangs loosely in the tube, so that it moves upwards and downwards perfectly free from friction, except that of the collar F E, where it is properly lubricated. When this plunger is allowed to descend by its weight into the water which fills the lower part of the tube, the valve *v* is closed, and the water displaced by the plunger is forced through the valve I into the tube E N. When the plunger is raised the valve I is closed, and the water thus forced into the tube E N cannot return. The water from the cistern then flows through the valve *v*, and rises in the tube to the level G. The next descent of the piston propels more water into the tube E N, and this is continued so long as the piston is worked.

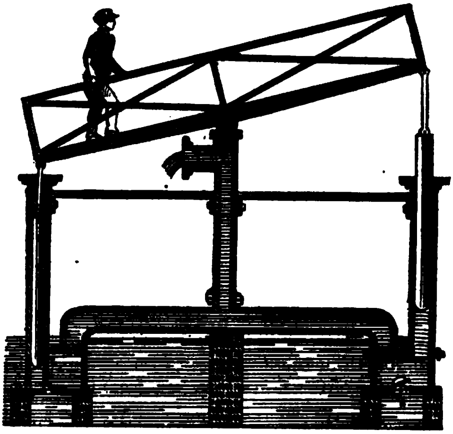
The manner in which such an apparatus is worked by the weight of a man, or any animal, is represented in fig. 7, p. 183. Two pumps are used, such as that just described, and when the plunger descends in one it rises in the other. The two pumps communicate with one vertical pipe, which therefore receives a continual supply of water; for while the action of one pump is suspended the other is in progress. A man walks from one end of an inclined plane to the other, and by his weight upon one side or the other of the fulcrum causes the plungers alternately to rise and fall.

9. Valves are of such constant use in all forms of pump, that it will be useful here briefly to explain their principal varieties.

A valve in general is a contrivance by which water or other fluid flowing through a tube or aperture is allowed free passage in one direction, but is stopped in the other. Its structure is such, that while the pressure of the fluid on one side has a tendency to close it, the pressure on the other side has a tendency to open it.

As in all forms of pump the water is required to be moved upwards, all the valves necessarily open upwards and close downwards.

Fig. 7.



There are several varieties of form.

10. The clack valve is like the lid of a box (fig. 8). It opens upwards, playing upon a hinge, and when the water presses it downwards it is closed.

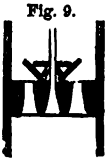
Fig. 8.

The single clack valve is the most simple example of the class. It is usually constructed by attaching to a plate of metal larger than the aperture which the valve is intended to stop, a piece of leather, and to the under side of this leather another piece of metal smaller than the aperture. The leather extending on one side beyond the larger metallic plate, and being flexible, forms the hinge on which the valve plays. Such a valve is usually closed by its own weight, and opened by the pressure of the fluid which passes through it. It is also held closed more firmly by the pressure of the fluid whose return it is intended to obstruct.

The extent to which such a valve should be capable of opening, ought to be such that the aperture produced by it shall be equal to the aperture which it stops. This will be effected if the angle through which it rises be about 30°.

A double clack consists of two semicircular plates, having the hinges on the diameters of the semicircles, as represented in fig. 9.

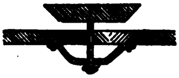
Fig. 9.



Of the valves which are opened by a motion perpendicular to their seat, the most simple is a flat metallic plate, made larger than the orifice which it is intended to stop, and ground so as to rest in water-tight contact with the surface surrounding the aperture. Such a valve is usually guided in its perpendicular motion by a spindle passing through its centre, and sliding in holes made in cross bars extending above and below the seat of the valve.

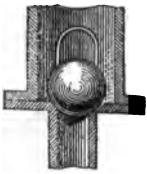
11. The conical valves, usually called spindle-valves (fig. 10), are the most common of this class. The best angle to be given to the conical seat is found in practice to be 45°. With a less inclination the valve has a tendency to be fastened in its seat, and a greater inclination would cause the top of the valve to occupy unnecessary space in the valve-box. The area, or transverse section of the valve-box, should be rather more than double the magnitude of the upper surface of the valve, and the play of the valve should be such as to allow it to rise from its seat to a height not less than one-fourth of the diameter of its upper surface.

Fig. 10.



12. The valves coming under this class are sometimes formed as spheres or hemispheres (fig. 11) resting in a conical seat, and in such cases they are generally closed by their own weight, and opened by the pressure of the fluid which passes through them.

Fig. 11.

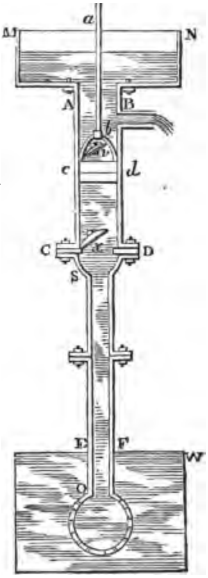


13. The several expedients already described are, however, greatly surpassed in convenience by the form of pump almost universally used in domestic and general economy, and known as the sucking or suction pump.

A section of this useful apparatus is shown in fig. 12, p. 169. It consists of a pipe or barrel, S O, which descends into the well, and the length of which must not exceed 32 feet. Attached to the top of this pipe, which is called the suction-pipe, is a large syringe, acting precisely on the principle of a common exhausting syringe.

At the commencement of the operation, the pipe S E is filled with air to the level of the water in the well. The operation of the syringe draws the chief part of the air out of this pipe S E. When the water within the pipe is partially relieved from the atmospheric pressure, the weight of the atmosphere, acting upon the external surface of the water in the well, forces it up in the pipe S E; and according as the air is withdrawn by the syringe, the water continues to rise, until it passes through the valve *x*. This valve opening upwards, prevents its return, since the weight of the column above it will keep it closed. When the barrel A C becomes filled with water, the syringe no longer acts as such, but works on the principle of the lifting pump, already explained. When the piston descends, the valve x is closed and the valve v opened, the water passing through the piston. When the piston is raised, the valve v is closed, and the column of water above the piston is projected upwards.

Fig. 12.



Meanwhile the pressure of the atmosphere on the water in the well causes more water to rise in the pump-barrel following the piston.

The atmospheric pressure is capable of supporting a column of about 34 feet of water.* It is evident, therefore, that such a pump as is here described can only be efficient when the piston is at a height of less than 34 feet above the surface of the water in the well, since otherwise the atmospheric pressure would not keep the water in contact with the piston.

The suction-pump, therefore, as compared with the lifting-pump, saves 34 feet length of pump rod; but otherwise there is no comparative mechanical advantage.

It might appear at first view that the pressure of the atmosphere sustaining a column of water in the suction-pipe, supplies aid to the power that works the pump, and spares an equivalent amount of that power.

This, however, is not the case, as will appear from a due consideration of all the forces which are in operation.

14. Of these forces there are some which are directed downwards from the top of the column raised by the piston towards the bottom of the well, and others which are directed upwards. Now it is evident that the mechanical power applied to draw the piston up will have to overcome all that excess by which the forces downwards exceed the forces upwards. Let us suppose a column of water resting on the piston, after having passed through the valve v. The upper surface of this column is pressed upon by the weight of the atmosphere; the piston has, therefore, this

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* See Tract on Barometer (10).

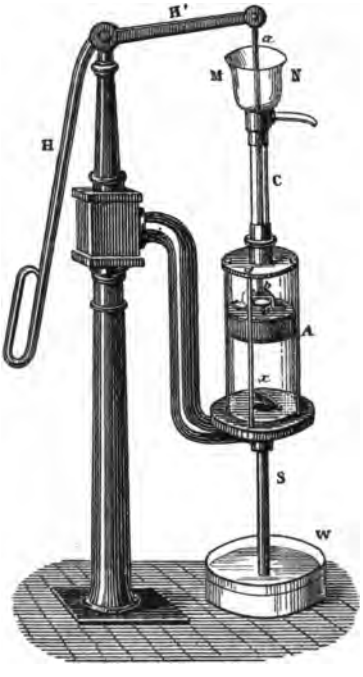
weight to sustain. It has also to sustain the weight of the water which is above it. The atmospheric pressure acting also on the water in the well, is transmitted by the water to the bottom of the piston; but this effect is diminished by the weight of the column of water between the surface of the water in the well and the bottom of the piston, for the atmospheric pressure must, in the first place, sustain that column, and can only act upon the bottom of the piston in the upward direction with that amount of force by which it exceeds the weight of the column of water between the piston and the well. The effect, therefore, on the piston is the same as if it were pressed downwards by the weight of the column of water between the piston and the well, and at the same time pressed upwards by the atmospheric pressure. Thus the piston may, in fact, be regarded as being urged downwards by the following forces,—the atmospheric pressure, the weight of the water above the piston, and the weight of the water between the piston and the well; that is to say, in fact, by the atmospheric pressure, together with the weight of all the water which has been raised from the well. At the same time, it is pressed upwards by the atmospheric pressure transmitted from the surface of the water in the well. This upward pressure will destroy the effect of the same atmospheric pressure acting downwards on the surface of the water above the piston, and the effective downward force will be the weight of all the water which is contained in the pump.

By this reasoning, it appears that the pump must be worked with as much force as is equal to the weight of all the water which is in it at any time, and, therefore, that the atmospheric pressure affords no aid to the working power.

Since the action of the pump in raising water is subject to intermission, the stream discharged from the spout will necessarily flow by fits and irregularly, if some means be not adopted to prevent this. At the top of the pump a cistern may be constructed, as shown in fig. 12, with a view to remove this inconvenience. If the pump be worked, in the first instance, so as to raise more water in a given time than is discharged at the spout, the column of water will necessarily accumulate in the barrel of the pump above the spout. The cistern M N will, therefore, be filled, and this will continue until the elevation of the surface of the water in the cistern above the spout will produce such a pressure, that the velocity of discharge from the spout will be equal to the velocity with which the water is raised by the piston. The level of the water in the cistern will therefore cease to rise. This level, however, will be subject to a small variation as the piston rises; for while the piston is descending, the water is flowing from the spout, and no water is raised by the piston, consequently the level of the water in the cistern falls. When the piston rises, water is raised, and the quantity in the cistern is increased faster than it flows from the spout, consequently the level of the water in the cistern rises, and thus this level alternately rises and falls with the piston. But if the magnitude of the cistern be much greater than the section of the pump-barrel, then this variation in the surface will be proportionally small, for the quantity of water which fills a part of the barrel, equal to the play of the piston, will produce a very slight change in the surface of the water in the cistern. The flow, therefore, from the spout will be uniform, or nearly so.

The action of this sort of pump will be rendered still more easily intelligible by fig. 13, which represents the working model of a suction-pump usually provided for demonstrations in popular lectures. The pump-handle H H′ raises and lowers the piston rod *a*. The pump-barrel is formed of glass, so as to show the

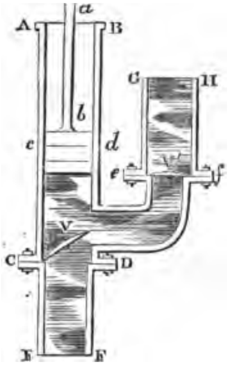
Fig. 13.



piston within it, having a valve opening upwards. The other parts of the apparatus are marked with letters corresponding with those of fig. 12.

15. Another form of pump, called the forcing-pump, is attended with many advantages, and is extensively used. This instrument is represented in fig. 14. The suction-pipe C E is similar to the suction-pump. The piston *c d* is a solid plug without a valve.

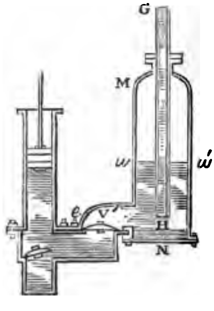
Fig. 14.



The forcing-pipe G H has at its base *e f* a valve V′ which opens upwards. When the piston *c d* is raised, the valve V is opened, and the water rises from the suction-pipe into the pump-barrel. When the piston *c d* is pressed downwards, the valve V is closed, and the water is forced by the pressure of the piston through the valve V′ into the force-pipe, and thus while the operation is continued, at each upward motion of the piston, water is drawn from the suction-pipe into the pump-barrel, and at each downward motion it is forced from the pump-barrel into the force-pipe.

16. In order to produce a continued flow of water in the force-pipe, an air-vessel is often attached to force-pumps. Such an appendage is represented in fig. 15.

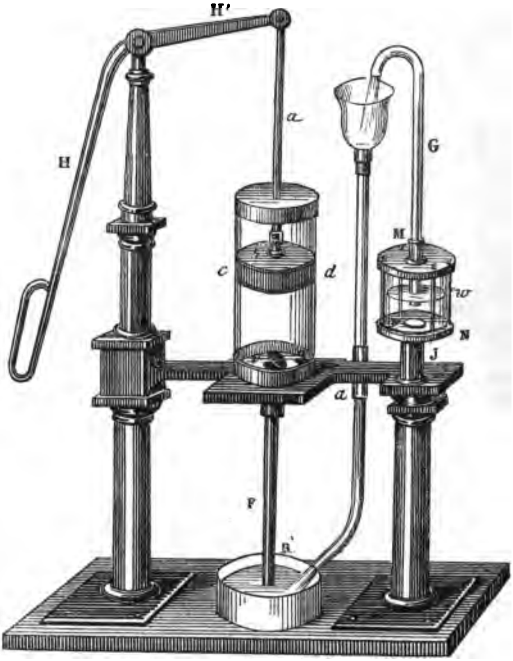
Fig. 15.



When the piston descends, the water is driven through the valve V′ into the vessel which is closed and contains air. The force-pipe G H descends into this vessel, and terminates near the bottom. The water which is forced in rises in it to a certain level, *w w′*, the air above it being compressed. The return of the water through the valve V′ being stopped, it is subject to the elastic pressure of the air confined in the air-vessel M N. This pressure forces the water through the tube H G from the top of which it issues in a constant stream.

The forcing-pump with its air-vessel, as constructed for demonstration at popular lectures, is shown in fig. 16, p. 189, where all the parts are indicated by the same letters as in figs. 14 and 15. The water which flows in a continual stream from the force-pipe G returns by the pipe P to the reservoir R, from which it is again raised by the pump.

Fig. 16.

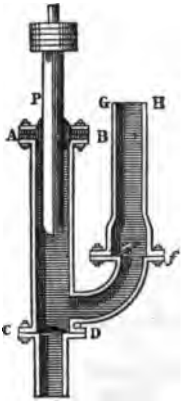


17. In the force-pump, where the water acts upon the piston with a great pressure, it is very important that the piston should move in complete water-tight contact with the pump-barrel. This is best accomplished by an accurately formed metallic plunger, P, fig. 17, working through a collar of leather, A B, which is exactly fitted to it, and with which it is made air-tight and water-tight, by being lubricated with oil or tallow. When this plunger is raised, the space it deserts is filled by the water which rises through the valve V, and when it descends, the water which filled the space into which it advances, is driven before it through the valve V into the force-pipe.

18. If the forcing-pump, represented in fig. 16, be attentively considered, it will be perceived that the principles on which the piston acts, in its ascent and descent, are perfectly distinct. In

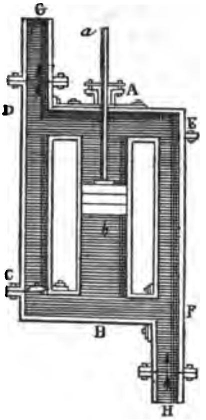
its ascent it is employed in drawing the water from the suction-pipe into the pump-barrel, and in its descent it is employed in forcing that water from the pump-barrel into the force-pipe. Now the piston being solid, and not furnished with any valve, there is no reason why its upper surface should not be employed in raising or propelling water as well as the lower. While the lower surface is employed in drawing water from the suction-pipe, the upper surface might be employed in propelling water into the force-pipe; and, on the other hand, in the descent of the piston, when the lower surface is employed in propelling water into the force-pipe, the upper surface might be engaged in drawing water from the suction-pipe. To accomplish this, it is only necessary that the top of the cylinder should be closed, and that the piston-rod should play through an air-tight collar, the top of the cylinder communicating with the force-pipe and the suction-pipe, as well as the bottom.

Fig. 17.



Such an arrangement is represented in fig. 18. When the piston ascends, the suction-valve F is opened, and water is drawn into the pump-barrel below the piston; and when the piston descends, the suction-valve F is closed, and the pressure of the piston on the water below it opens the valve C, and propels the water into the force-pipe C G. Also, while the piston is descending, water rises through the suction-valve E into the barrel above the piston; and when the piston ascends, the water being pressed upwards keeps the valve E closed, and opens the valve D, and is thus propelled into the force-pipe. By this arrangement the force-pipe receives a continual supply of water from the pump-barrel without any intermission; and in like manner the pump-barrel receives an unremitting flow from the suction-pipe. This will be distinctly seen, if it is considered that either of the two valves E or F must always be open. If the piston go down E is open and F

Fig. 18.



closed; if it go up E is closed and F open. A stream, therefore, continually flows through one valve or the other into the pump-barrel. In like manner, whether the piston ascend or descend, one of the valves, C or D, must be open.

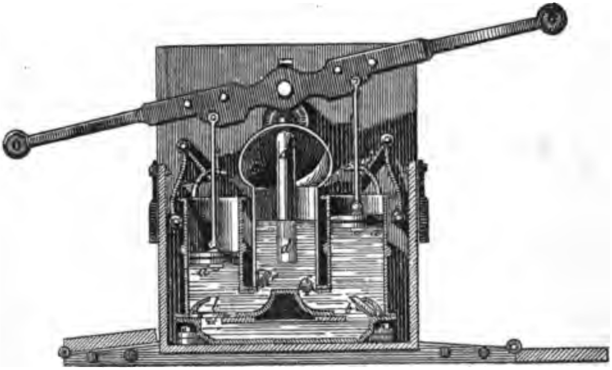
19. The simple pumps used for watering gardens are shown in fig. 19, at the head of this tract, a single or double-action force-pump projecting a jet of water over the ground to be irrigated.

20. The fire-engine is a double forcing-pump, each barrel of which acts upon the principle explained above.

A section of such an engine, in its most usual form, is represented in fig. 20.

The solid pistons *a a* are alternately forced down upon the water which has been drawn into the barrels upon the principles already explained, and the water is thus forced into the air vessel *e*. The reaction of the compressed air drives the water with a proportionate force through the force-pipe *d* into a long, flexible, leathern hose, upon the end of which a large jet-pipe is screwed. The firemen carry this jet-pipe near to or into the building on fire, and with it throw up to great heights a constant stream of water, which, falling on the burning bodies, extinguishes the fire.

Fig. 20.



21. A form of lifting-pump, called the chain-pump, is commonly used to discharge the water from the hold of ships of war and other vessels of the large class. This pump consists of an endless chain which passes over two rollers, one of which is established on the deck, above the level at which the water is to be discharged, and the other at the bottom of the hold. Attached to the chain, and placed at right angles with it, are a series of saucers, or a sort

of flat circular plates, one above the other, by which the water is lifted. These saucers lift the water and press it up through a vertical pipe placed near the ascending side of the chain. The water, rising through this pipe, is discharged into a cistern on the deck, from which it flows off into the sea through a waste pipe called the *pump-dale.*

There are two hollow vertical barrels, or cases, through one of which the chain ascends, and through the other it descends. The chain is worked by means of a winch attached to the upper roller, over which it passes. This winch receives a continual motion of rotation, by the power of men applied to its handles, which are so formed that several men can work them simultaneously.

In large vessels these pumps are constructed upon a scale sufficient to enable them to raise a ton of water, or about 250 gallons per minute.

22. The purpose to which pumps are applied on the most vast scale is in the drainage of mines. In that case the power required far exceeds the limit to which animal power is practically available, and even steam-power, by which such pumps are worked, requires to be applied on a scale far exceeding every other form in which it has been applied in the industrial arts.

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